

COMPOSITIONS COMPRISING HYDROGENATED BLOCK COPOLYMERS AND
END-USE APPLICATIONS THEREOF

This application is a Continuation in Part application from copending U.S.
5 application 09/575,062, filed on May 19, 2000, which claims benefit of U.S.
Provisional Application No. 60/139,074, filed on June 11, 1999, U.S. Provisional
Application No. 60/146,008, filed on July 28, 1999, and U.S. Provisional Application
No. 60/193,313, filed on March 30, 2000.

This invention relates to compositions of hydrogenated block copolymers.

10 BACKGROUND OF THE INVENTION

Partially hydrogenated block copolymers of vinyl aromatic and conjugated
dienes such as hydrogenated styrene-butadiene-styrene copolymers are well known in
the art. U.S. Patent Nos. 3,333,024; 3,431,323; 3,598,886; 5,352,744; 3,644,588 and
EP-505,110 disclose various hydrogenated block copolymers. Partially hydrogenated
15 refers to hydrogenation of the diene portion of the block copolymer without aromatic
hydrogenation or aromatic hydrogenation of 90 percent or less. Although these
partially hydrogenated copolymers have been tested in various applications, they suffer
from one or more shortcomings, including low heat resistance, poor physical properties,
poor processability, low heat resistance and poor light stability. Attempts have been
20 made to remedy these shortcomings by increasing the hydrogenation of the aromatic
ring of the block copolymer. However, polymer scientists contend that fully
hydrogenated styrene-butadiene-styrene copolymers have no useful properties at
elevated temperatures, even if only slightly elevated. Thermoplastic Elastomers, 2nd
edition, 1996, page 304, lines 8-12 states "Thus, polystyrene remains the choice for any
25 amorphous hydrocarbon block copolymer. This last fact is clearly demonstrated in the
case of the fully hydrogenated VCH-EB-VCH polymer. The interaction parameter is so
severely reduced by hydrogenation that at only slightly elevated temperatures, the
polymer loses all strength and appears to be homogeneously mixed at ordinary melt
temperatures."

Specifically, hydrogenated diblock copolymers tend to have low viscosities and melt strengths making them difficult to process. Diblocks also have other disadvantages due to their poor tensile properties. For the same reason they are not useful for making flexible materials, while rigid materials made from diblocks tend to be brittle.

Blends of partially hydrogenated block copolymers with other polymers are also known. For example, blends of cyclic olefin (co)polymers have been attempted as disclosed in EP-0726291, wherein cyclic olefin (co)polymers are blended with vinyl aromatic/conjugated diene block copolymers or hydrogenated versions thereof. Cyclic olefin (co)polymers (COC's) are known to have excellent heat distortion temperature, UV stability and processability. However, such copolymers suffer from poor impact resistance. Blends of COC's with partially hydrogenated block copolymers still suffer from an imbalance of physical properties due to the absence of aromatic hydrogenation within the block copolymer.

Therefore, there remains a need for compositions of fully or substantially hydrogenated block copolymers which have adequate viscosity and melt strength to ease processability, can be used in elastomeric applications and have a desirable balance of physical properties.

Additionally, uses for clear, substantially or fully hydrogenated hydrogenated block copolymers of vinyl aromatic and conjugated diene monomers, and polymer blends thereof, are still desired, wherein the copolymers are processable by conventional manufacturing technologies and possess useful physical properties at standard and elevated temperatures.

SUMMARY OF THE INVENTION

One aspect of the present invention is directed to compositions comprising fully or substantially hydrogenated block copolymers and various end-use applications thereof. The hydrogenated block copolymer is a rigid hydrogenated block copolymer, which comprises at least two distinct blocks of hydrogenated polymerized vinyl

aromatic monomer, herein referred to as hydrogenated vinyl aromatic polymer blocks, and at least one block of hydrogenated polymerized conjugated diene monomer, herein referred to as hydrogenated conjugated diene polymer block, wherein the hydrogenated copolymer is further characterized by:

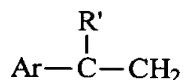
- 5 a) a weight ratio of hydrogenated conjugated diene polymer block to hydrogenated vinyl aromatic polymer block of 40:60 or less;
- b) a total number average molecular weight (M_n) of from 30,000 to 150,000, wherein each hydrogenated vinyl aromatic polymer block (A) has a M_{n_a} of from 6,000 to 60,000 and each hydrogenated conjugated diene polymer block (B) has a M_{n_b} of from 3,000 to 30,000; and
- 10 c) a hydrogenation level such that each hydrogenated vinyl aromatic polymer block has a hydrogenation level of greater than 90 percent and each hydrogenated conjugated diene polymer block has a hydrogenation level of greater than 95 percent.

- 15 Hydrogenated block copolymers having these M_n and hydrogenation characteristics are transparent to light at visible wavelengths and are ideally suited for various applications, while possessing excellent properties at both standard and elevated temperatures. The combination of transparency, high glass transition temperature, low water absorption, good strength, toughness, weatherability and
- 20 excellent melt processability makes these materials and blends thereof, ideal candidates for many applications including fabricated articles, thermoformed articles, extruded articles, injection molded articles, films and the like.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

- 25 One aspect of the present invention is directed to applications for rigid hydrogenated block copolymers and end-use applications thereof. Hydrogenated block copolymers are prepared by hydrogenating a block copolymer produced from a vinyl aromatic monomer and a conjugated diene monomer.

The vinyl aromatic monomer is typically a monomer of the formula



wherein R' is hydrogen or alkyl, Ar is phenyl, halophenyl, alkylphenyl, alkylhalophenyl, naphthyl, pyridinyl, or anthracenyl, wherein any alkyl group contains 1
5 to 6 carbon atoms which may be mono or multisubstituted with functional groups such as halo, nitro, amino, hydroxy, cyano, carbonyl and carboxyl. More preferably Ar is phenyl or alkyl phenyl with phenyl being most preferred. Typical vinyl aromatic monomers include styrene, alpha-methylstyrene, all isomers of vinyl toluene, especially paravinyltoluene, all isomers of ethyl styrene, propyl styrene, butyl styrene, vinyl
10 biphenyl, vinyl naphthalene, vinyl anthracene and the like, and mixtures thereof. The block copolymer can contain more than one specific polymerized vinyl aromatic monomer. In other words, the block copolymer can contain a polystyrene block and a poly-alpha-methylstyrene block. The hydrogenated vinyl aromatic polymer block can also be a copolymer wherein the hydrogenated vinyl aromatic component is at least 50
15 weight percent of the copolymer.

The conjugated diene monomer can be any monomer having 2 conjugated double bonds. Such monomers include for example 1,3-butadiene, 2-methyl-1,3-butadiene, 2-methyl-1,3 pentadiene, isoprene and similar compounds, and mixtures thereof. The block copolymer can contain more than one specific polymerized
20 conjugated diene monomer. In other words, the block copolymer can contain a polybutadiene block and a polyisoprene block.

The conjugated diene polymer block can be prepared from materials which remain amorphous after the hydrogenation process, or materials which are capable of crystallization after hydrogenation. Hydrogenated polyisoprene blocks remain
25 amorphous, while hydrogenated polybutadiene blocks can be either amorphous or crystallizable depending upon their structure. Polybutadiene can contain either a 1,2 configuration, which hydrogenates to give the equivalent of a 1-butene repeat unit, or a

1,4-configuration, which hydrogenates to give the equivalent of an ethylene repeat unit. Polybutadiene blocks having at least approximately 40 weight percent 1,2-butadiene content, based on the weight of the polybutadiene block, provides substantially amorphous blocks with low glass transition temperatures upon hydrogenation.

- 5 Polybutadiene blocks having less than approximately 40 weight percent 1,2-butadiene content, based on the weight of the polybutadiene block, provide crystalline blocks upon hydrogenation. Depending on the final application of the polymer it may be desirable to incorporate a crystalline block (to improve solvent resistance) or an amorphous, more compliant block. In some applications, the block copolymer can
- 10 contain more than one conjugated diene polymer block, such as a polybutadiene block and a polyisoprene block. The conjugated diene polymer block may also be a copolymer of a conjugated diene, wherein the conjugated diene portion of the copolymer is at least 50 weight percent of the copolymer. The conjugated diene polymer block may also be a copolymer of more than one conjugated diene, such as a
- 15 copolymer of butadiene and isoprene.

Other polymeric blocks may also be included in the hydrogenated block copolymers of the present invention.

- A block is herein defined as a polymeric segment of a copolymer which exhibits microphase separation from a structurally or compositionally different polymeric
- 20 segment of the copolymer. Microphase separation occurs due to the incompatibility of the polymeric segments within the block copolymer. Microphase separation and block copolymers are widely discussed in "Block Copolymers-Designer Soft Materials", PHYSICS TODAY, February, 1999, pages 32-38.

- The rigid hydrogenated block copolymers are defined as having a weight ratio of
- 25 hydrogenated conjugated diene polymer block to hydrogenated vinyl aromatic polymer block of 40:60 or less, typically from 40:60 to 5:95, preferably from 35:65 to 10:90, more preferably from 30:70 to 15:85, based on the total weight of the hydrogenated conjugated diene polymer block and the hydrogenated vinyl aromatic polymer block. The total weights of the hydrogenated vinyl aromatic polymer blocks and the

hydrogenated conjugated diene polymer block(s) is typically at least 80 weight percent, preferably at least 90, and more preferably at least 95 weight percent of the total weight of the hydrogenated copolymer.

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The rigid hydrogenated block copolymers used in the present invention are produced by the hydrogenation of block copolymers including triblock, multiblock, tapered block, and star block copolymers such as SBS, SBSBS, SIS, SISIS, SISBS and the like (wherein S is polystyrene, B is polybutadiene and I is polyisoprene). The block copolymers contain at least one triblock segment comprised of a vinyl aromatic polymer block on each end. The block copolymers may, however, contain any number of additional blocks, wherein these blocks may be attached at any point to the triblock polymer backbone. Thus, linear blocks would include for example SBS, SBSB, SBSBS, SBSBSB, and the like. The copolymer can also be branched, wherein polymer chains are attached at any point along the copolymer backbone. It should be noted here that in the production of block copolymers, it is expected that small amounts of residual diblock copolymers are also produced.

The total number average molecular weight (M_n) of the rigid hydrogenated block copolymers used in the present invention is typically from 24,000, preferably from 30,000, more preferably from 45,000 and most preferably from 50,000 to 150,000, typically to 135,000, generally to 115,000, preferably to 100,000, more preferably to 90,000, and most preferably to 85,000. The M_n , as referred to throughout this specification, is determined by gel permeation chromatography (GPC). The molecular weight of the rigid hydrogenated block copolymer and properties obtained are dependent upon the molecular weight of each of the hydrogenated polymeric blocks.

Number average molecular weight (M_n) and weight average molecular weight (M_w) can both be used to describe the polymers described herein. Because these polymers tend to have very narrow molecular weight polydispersities, the difference between M_n and M_w will be minimal. The ratio of M_w to M_n is typically 1.1 or less. In fact, in some cases the number average molecular weight and the number average

molecular weight will be virtually the same. Therefore, M_n can also be read as M_w throughout this application.

It should be noted that good properties are obtained at hydrogenated vinyl aromatic polymer molecular weights which are lower than the entanglement molecular weight of the hydrogenated vinyl aromatic polymer. The entanglement molecular weight of a polymer is associated with the chain length required for a given polymer to show a dramatic increase in melt viscosity due to chain entanglements. The entanglement molecular weights for many common polymers have been measured and reported in Macromolecules, 1994, Volume 27, page 4639. It is commonly observed for glassy polymers that maximum values of strength and toughness are achieved at about 10 times the entanglement molecular weight (see, for instance, Styrene Polymers in the Encyclopedia of Polymer Science and Engineering, 2nd edition, Volume 16, pages 62-71, 1989). The entanglement molecular weight is approximately 38,000 for hydrogenated polystyrene (polyvinylcyclohexane). We have determined that an optimum balance of properties and processability can be obtained at hydrogenated vinyl aromatic polymer block molecular weights (M_n) of 0.2 to 1.2 times the entanglement molecular weight of a hydrogenated vinyl aromatic polymer.

The M_{n_a} of the rigid hydrogenated vinyl aromatic polymer block will typically be from 6,000, preferably from 10,000, more preferably from 15,000 and most preferably from 20,000 to 60,000, preferably to 50,000, more preferably to 45,000 and most preferably to 40,000. The hydrogenated diene polymer block will typically have a M_{n_b} from 4,000, preferably from 8,000, more preferably from 10,000, and most preferably from 12,000 to 30,000, preferably to 28,000, most preferably to 25,000 and most preferably to 22,000.

It is important to note that each individual block of the rigid hydrogenated block copolymer of the present invention, can have its own distinct M_n . In other words, for example, two hydrogenated vinyl aromatic polymer blocks within the hydrogenated block copolymer may each have a different M_n .

Methods of making block copolymers are well known in the art. Typically, block copolymers are made by anionic polymerization, examples of which are cited in Anionic Polymerization: Principles and Practical Applications, H.L. Hsieh and R.P. Quirk, Marcel Dekker, New York, 1996. In one embodiment, block copolymers are made by sequential monomer addition to a carbanionic initiator such as sec-butyl lithium or n-butyl lithium. In another embodiment, the copolymer is made by coupling a triblock material with a divalent coupling agent such as 1,2-dibromoethane, dichlorodimethylsilane, or phenylbenzoate. In this embodiment, a small chain (less than 10 monomer repeat units) of a conjugated diene polymer can be reacted with the vinyl aromatic polymer coupling end to facilitate the coupling reaction. Vinyl aromatic polymer blocks are typically difficult to couple, therefore, this technique is commonly used to achieve coupling of the vinyl aromatic polymer ends. The small chain of diene polymer does not constitute a distinct block since no microphase separation is achieved. Coupling reagents and strategies which have been demonstrated for a variety of anionic polymerizations are discussed in Hsieh and Quirk, Chapter 12, pgs. 307-331. In another embodiment, a difunctional anionic initiator is used to initiate the polymerization from the center of the block system, wherein subsequent monomer additions add equally to both ends of the growing polymer chain. An example of a such a difunctional initiator is 1,3-bis(1-phenylethenyl) benzene treated with organolithium compounds, as described in U.S. Patents 4,200,718 and 4,196,154 which are herein incorporated by reference.

After preparation of the block copolymer, the copolymer is hydrogenated to remove sites of unsaturation in both the conjugated diene polymer block and the vinyl aromatic polymer block segments of the copolymer. Any method of hydrogenation can be used and such methods typically include the use of metal catalysts supported on an inorganic substrate, such as Pd on BaSO₄ (U.S. Patent 5,352,744) and Ni on kieselguhr (U.S. Patent 3,333,024) both of which are incorporated herein by reference. Additionally, soluble, homogeneous catalysts such those prepared from combinations of transition metal salts of 2-ethylhexanoic acid and alkyl lithiums can be used to fully saturate block copolymers, as described in Die Makromolekulare Chemie, Volume 160,

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pp. 291, 1972. The copolymer hydrogenation can also be achieved using hydrogen and a heterogeneous catalyst such as those described in U.S. patents 5,352,744, U.S. 5,612,422 and U.S. 5,645,253 which are herein incorporated by reference. The catalysts described therein are heterogeneous catalysts consisting of a metal crystallite supported
5 on a porous silica substrate. An example of a silica supported catalyst which is especially useful in the polymer hydrogenation is a silica which has a surface area of at least 10 m²/g which is synthesized such that it contains pores with diameters ranging between 3000 and 6000 angstroms. This silica is then impregnated with a metal capable of catalyzing hydrogenation of the polymer, such as nickel, cobalt, rhodium,
10 ruthenium, palladium, platinum, other Group VIII metals, combinations or alloys thereof. Other heterogeneous catalysts can also be used, having diameters in the range of 500 to 3,000 angstroms.

Alternatively, the hydrogenation can be conducted in the presence of a mixed hydrogenation catalyst characterized in that it comprises a mixture of at least two
15 components. The first component comprises any metal which will increase the rate of hydrogenation and includes nickel, cobalt, rhodium, ruthenium, palladium, platinum, other Group VIII metals, or combinations thereof. Preferably rhodium and/or platinum is used. The second component used in the mixed hydrogenation catalyst comprises a promoter which inhibits deactivation of the Group VIII metal(s) upon exposure to polar
20 materials, and is herein referred to as the deactivation resistant component. Such components preferably comprise rhenium, molybdenum, tungsten, tantalum or niobium or mixtures thereof.

The amount of the deactivation resistant component in the mixed catalyst is at least an amount which significantly inhibits the deactivation of the Group VIII metal
25 component when exposed to polar impurities within a polymer composition, herein referred to as a deactivation inhibiting amount. Deactivation of the Group VIII metal is evidenced by a significant decrease in hydrogenation reaction rate. This is exemplified in comparisons of a mixed hydrogenation catalyst and a catalyst containing only a Group VIII metal component under identical conditions in the presence of a polar
30 impurity, wherein the catalyst containing only a Group VIII metal component exhibits a

hydrogenation reaction rate which is less than 75 percent of the rate achieved with the mixed hydrogenation catalyst.

Preferably, the amount of deactivation resistant component is such that the ratio of the Group VIII metal component to the deactivation resistant component is from 0.5:1 to 10:1, more preferably from 1:1 to 7:1, and most preferably from 1:1 to 5:1.

The mixed catalyst can consist of the components alone, but preferably the catalyst additionally comprises a support on which the components are deposited. In one embodiment, the metals are deposited on a support such as a silica, alumina or carbon. In a more specific embodiment, a silica support having a narrow pore size distribution and surface area greater than 10 meters squared per gram (m^2/g) is used.

The pore size distribution, pore volume, and average pore diameter of the support can be obtained via mercury porosimetry following the proceedings of ASTM D-4284-83.

The pore size distribution is typically measured using mercury porosimetry. However, this method is only sufficient for measuring pores of greater than 60 angstroms. Therefore, an additional method must be used to measure pores less than 60 angstroms. One such method is nitrogen desorption according to ASTM D-4641-87 for pore diameters of less than about 600 angstroms. Therefore, narrow pore size distribution is defined as the requirement that at least 98 percent of the pore volume is defined by pores having pore diameters greater than 300 angstroms and that the pore volume measured by nitrogen desorption for pores less than 300 angstroms, be less than 2 percent of the total pore volume measured by mercury porosimetry.

The surface area can be measured according to ASTM D-3663-84. The surface area is typically between 10 and 100 m^2/g , preferably between 15 and 90 with most preferably between 50 and 85 m^2/g .

The desired average pore diameter of the support for the mixed catalyst is dependent upon the polymer which is to be hydrogenated and its molecular weight. It is preferable to use supports having higher average pore diameters for the

hydrogenation of polymers having higher molecular weights to obtain the desired amount of hydrogenation. For high molecular weight polymers ($M_n > 200,000$ for example), the typical desired surface area can vary from 15 to 25 m^2/g and the desired average pore diameter from 3,000 to 4000 angstroms. For lower molecular weight polymers ($M_n < 100,000$ for example), the typical desired surface area can vary from 45 to 85 m^2/g and the desired average pore diameter from 300 to 700 angstroms.

Silica supports are preferred and can be made by combining potassium silicate in water with a gelation agent, such as formamide, polymerizing and leaching as exemplified in U.S. Patent No. 4,112,032. The silica is then hydrothermally calcined as in Iler, R.K., The Chemistry of Silica, John Wiley and Sons, 1979, pp. 539-544, which generally consists of heating the silica while passing a gas saturated with water over the silica for about 2 hours or more at temperatures from about 600°C to about 850°C. Hydrothermal calcining results in a narrowing of the pore diameter distribution as well as increasing the average pore diameter. Alternatively, the support can be prepared by processes disclosed in Iler, R.K., The Chemistry of Silica, John Wiley and Sons, 1979, pp. 510-581.

A silica supported catalyst can be made using the process described in U.S. Patent No. 5,110,779, which is incorporated herein by reference. An appropriate metal, metal component, metal containing compound or mixtures thereof, can be deposited on the support by vapor phase deposition, aqueous or nonaqueous impregnation followed by calcination, sublimation or any other conventional method, such as those exemplified in Studies in Surface Science and Catalysis, "Successful Design of Catalysts" V. 44, pg. 146-158, 1989 and Applied Heterogeneous Catalysis pgs. 75-123, Institute Français du Pétrole Publications, 1987. In methods of impregnation, the appropriate metal containing compound can be any compound containing a metal, as previously described, which will produce a usable hydrogenation catalyst which is resistant to deactivation. These compounds can be salts, coordination complexes, organometallic compounds or covalent complexes.

Typically, the total metal content of the mixed supported catalyst is from 0.1 to 10 wt. percent based on the total weight of the silica supported catalyst. Preferable amounts are from 2 to 8 wt. percent, more preferably 0.5 to 5 wt. percent based on total catalyst weight.

- 5 Promoters, such as alkali, alkali earth or lanthanide containing compounds, can also be used to aid in the dispersion of the metal component onto the silica support or stabilization during the reaction, though their use is not preferred.

- 10 The amount of mixed supported catalyst used in the hydrogenation process is much smaller than the amount required in conventional unsaturated polymer hydrogenation reactions due to the high reactivity of the hydrogenation catalysts. Generally, amounts of less than 1 gram of supported catalyst per gram of unsaturated polymer are used, with less than 0.1 gram being preferred and less than 0.05 being more preferred. The amount of supported catalyst used is dependent upon the type of process, whether it is continuous, semi-continuous or batch, and the process conditions, such as temperature, pressure and reaction time wherein typical reaction times may vary from about 5 minutes to about 5 hours. Continuous operations can typically contain 1 part by weight supported catalyst to 200,000 or more parts unsaturated polymer, since the supported catalyst is reused many times during the course of continuous operation. Typical batch processes can use 1 part by weight supported catalyst to 5,000 parts unsaturated polymer. Higher temperatures and pressures will also enable using smaller amounts of supported catalyst.
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- 25 The hydrogenation reaction can be conducted in the absence of a solvent but is preferably conducted in a hydrocarbon solvent in which the polymer is soluble and which will not hinder the hydrogenation reaction. Preferably the solvent is a saturated solvent such as cyclohexane, methylcyclohexane, ethylcyclohexane, cyclooctane, cycloheptane, dodecane, dioxane, diethylene glycol dimethyl ether, tetrahydrofuran, isopentane, decahydronaphthalene or mixtures thereof, with cyclohexane being the most preferred.

Typical hydrogenation temperatures are from about 40°C preferably from about 100°C, more preferably from about 110°C, and most preferably from about 120°C to about 250°C, preferably to about 200°C, more preferably to about 180°C, and most preferably to about 170°C.

5 The pressure of the hydrogenation reaction is not critical, though hydrogenation rates increase with increasing pressure. Typical pressures range from atmospheric pressure to 70 MPa, with 0.7 to 10.3 MPa being preferred.

 The reaction vessel is purged with an inert gas to remove oxygen from the reaction area. Inert gases include but are not limited to nitrogen, helium, and argon,
10 with nitrogen being preferred.

 The hydrogenating agent can be any hydrogen producing compound which will efficiently hydrogenate the unsaturated polymer. Hydrogenating agents include but are not limited to hydrogen gas, hydrazine and sodium borohydride. In a preferred embodiment, the hydrogenating agent is hydrogen gas.

15 Hydrogenated rigid block copolymers used in the present invention are also defined as being substantially or fully hydrogenated in that at least 90 percent of the aromatic rings of the block copolymer are hydrogenated, and may be referred to as substantially hydrogenated rigid block copolymers. The level of hydrogenation is preferably greater than 95 percent of the conjugated diene polymer block and greater
20 than 90 percent of the vinyl aromatic polymer block segments, more preferably greater than 99 percent of the conjugated diene polymer block and greater than 95 percent of the vinyl aromatic polymer block segments, even more preferably greater than 99.5 percent of the conjugated diene polymer block and greater than 98 percent of the vinyl aromatic polymer block segments, and most preferably greater than 99.9 percent of the
25 conjugated diene polymer block and 99.5 percent of the vinyl aromatic polymer block segments. The term 'level of hydrogenation' refers to the percentage of the original unsaturated bonds which become saturated upon hydrogenation. The level of hydrogenation in hydrogenated vinyl aromatic polymers is determined using UV-VIS

spectrophotometry, while the level of hydrogenation in hydrogenated diene polymers is determined using proton NMR.

Anionically polymerized block copolymers typically microphase separate into well-defined morphologies, with morphology dimensions typically ranging from 5 to 50 nanometers in size. Typical morphologies include a continuous matrix phase of one hydrogenated polymer with well-defined spheres, cylinders or gyroids of the minor phase hydrogenated polymer blocks dispersed within the matrix, and a lamellar cocontinuous phase, wherein both hydrogenated polymer blocks are in a continuous phase interspersed within each other. These different morphologies give rise to different physical properties. Hydrogenated block copolymers in which the hydrogenated conjugated diene polymer blocks are continuous are typically elastomeric, highly resilient materials. Conversely, materials in which the hydrogenated vinyl aromatic polymer block segments are the continuous phase are typically stiff, tough plastics. Hydrogenated block copolymers wherein both hydrogenated polymer blocks are cocontinuous tend to have intermediate properties.

In one embodiment, the composition comprises a hydrogenated block copolymer comprising less than 80 weight percent hydrogenated vinyl aromatic polymer blocks, based on the total weight of the hydrogenated block copolymer, and has an aromatic hydrogenation level of greater than 90 percent.

In another embodiment, the composition comprises a hydrogenated block copolymer of a vinyl aromatic and a conjugated diene, wherein the block copolymer is a pentablock copolymer comprising 3 blocks of hydrogenated vinyl aromatic polymer and two blocks of conjugated diene polymer. The hydrogenated pentablock copolymer comprises less than 80 weight percent hydrogenated vinyl aromatic polymer blocks, based on the total weight of the hydrogenated block copolymer, and has an aromatic hydrogenation level of greater than 90 percent.

Another aspect of the present invention relates to polymer blends of the hydrogenated rigid block copolymers.

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Compositions comprising hydrogenated rigid block copolymer (or substantially hydrogenated rigid block copolymer), may also comprise at least one other natural or synthetic polymer. Suitable polymeric materials include, but are not limited to, hydrogenated vinyl aromatic homopolymers, other hydrogenated block copolymers, including hydrogenated styrene/butadiene or styrene/isoprene block copolymers, thermoplastic polyurethanes, polycarbonates (PC), polyamides, polyethers, poly/vinyl chloride polymers, poly/vinylidene chloride polymers, polyesters, polymers that contain lactic acid residuals, partially or non-hydrogenated block copolymers, thermoplastics such as styrene-butadiene block copolymers, polystyrene (including high impact polystyrene), acrylonitrile-butadiene-styrene (ABS) copolymers, styrene-acrylonitrile copolymers (SAN), ABS/PC compositions, polyethylene terephthalate, epoxy resins, ethylene vinyl alcohol copolymers, ethylene acrylic acid copolymers, polyolefin carbon monoxide interpolymers, chlorinated polyethylene, cyclic olefin copolymers (COC's), olefin copolymers (especially polyethylene copolymers such as ethylene-styrene interpolymers) and homopolymers (e.g., those made using conventional heterogeneous catalysts). Examples include polymers made by the process of U.S. Patent 4,076,698, incorporated herein by reference.

In one embodiment, the composition additionally comprises a polyolefin elastomer or plastomer, especially a polyolefin elastomer or plastomer made using a single-site catalyst system (for example, a homogeneously branched ethylene polymer such as a substantially linear ethylene interpolymer or a homogeneously branched linear ethylene interpolymer).

Generally suitable polyolefins include, for example, polyethylene (ethylene homopolymer), ethylene/alpha-olefin interpolymers, alpha-olefin homopolymers, such as polypropylene(propylene homopolymer), alpha-olefin interpolymers, such as interpolymers of polypropylene and an alpha-olefin having at least 4 carbon atoms.

Representative polyolefins include, for example, but are not limited to, substantially linear ethylene polymers, homogeneously branched linear ethylene polymers, heterogeneously branched linear ethylene (including linear low density

polyethylene (LLDPE), ultra or very low density polyethylene (ULDPE or VLDPE) medium density polyethylene (MDPE) and high density polyethylene (HDPE)), high pressure low density polyethylene (LDPE), ethylene/acrylic acid (EAA) copolymers, ethylene/methacrylic acid (EMAA) copolymers, ethylene/acrylic acid (EAA) ionomers, 5 ethylene/methacrylic acid (EMAA) ionomers, ethylene/vinyl acetate (EVA) copolymers, ethylene/vinyl alcohol (EVOH) copolymers, polypropylene homopolymers and copolymers, ethylene/propylene polymers, ethylene/styrene interpolymers, graft-modified polymers (e.g., maleic anhydride grafted polyethylene such as LLDPE g-MAH), ethylene acrylate copolymers (e.g. ethylene/ethyl acrylate (EEA) copolymers, 10 ethylene/methyl acrylate (EMA), and ethylene/methmethyl acrylate (EMMA) copolymers), polybutylene (PB), ethylene carbon monoxide interpolpolymer (e.g., ethylene/carbon monoxide (ECO), copolymer, ethylene/acrylic acid/carbon monoxide (EAACO) terpolymer, ethylene/methacrylic acid/carbon monoxide (EMAACO) terpolymer, ethylene/vinyl acetate/carbon monoxide (EVACO) terpolymer and 15 styrene/carbon monoxide (SCO), chlorinated polyethylene and mixtures thereof.

Ethylene/styrene interpolymers are prepared by polymerizing i) ethylene or one or more alpha-olefin monomers and ii) one or more vinyl or vinylidene aromatic monomers and/or one or more sterically hindered aliphatic or cycloaliphatic vinyl or vinylidene monomers, and optionally iii) other polymerizable ethylenically unsaturated 20 monomer(s).

Ethylene/styrene interpolymers can be substantially random, psuedo-random, random, alternately, diadic, triadic, tetradic or any combination thereof. That is, the interpolpolymer product can be variably incorporated and optionally variably sequenced. Preferred ethylene/styrene interpolymers are substantially random ethylene/styrene 25 interpolymers.

The term "variably incorporated" as used herein refers to a ethylene/styrene interpolpolymer manufactured using at least two catalyst systems wherein during interpolpolymerization the catalyst systems are operated at different incorporation or reactivity rates. For example, the interpolpolymer product having a total styrene content of

36 weight percent is variably incorporated where one catalyst system incorporates 22 weight percent styrene and the other catalyst system incorporates 48 weight percent styrene and the production split between the two catalyst systems is 47/53 weight percentages.

5 “Pseudo-random” ethylene/styrene interpolymers are described in U.S. Patent 5,703,187, the disclosure of which is incorporated herein in its entirety by reference.

 “Random” interpolymers are those in which the monomer units are incorporated into the chain wherein there can exist various combinations of ordering including
10 blockiness where either the aliphatic alpha-olefin monomer (A) or hindered vinylidene monomer (B) or both can be repeated adjacent to one another.

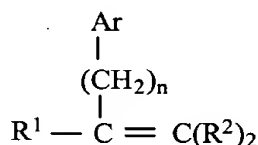
 “Alternating” ethylene/styrene interpolymers are those in which the aliphatic alpha-olefin monomer (A) and hindered vinylidene monomer (B) occur in repeat
15 alternate sequences on the polymer chain in atactic or stereospecific structures (such as isotactic or syndiotactic) or in combinations of the general formula $(AB)_n$, wherein n is an integer from 1 to 4000. The term “substantially random” as used herein in reference to ethylene/styrene interpolymers generally means that the distribution of the monomers of the interpolymers can be described by the Bernoulli statistical model or by a first or second order Markovian statistical model, as described by J. C. Randall in POLYMER
20 SEQUENCE DETERMINATION, Carbon-13 NMR Method, Academic Press New York, 1977, pp. 71-78. Substantially random interpolymers do not contain more than 15 mole percent of the total amount of vinyl or vinylidene aromatic monomer in blocks of vinyl or vinylidene aromatic monomer of more than 3 units.

 Preferably, the substantially random interpolymers are not characterized by a high
25 degree (greater than 50 mol%) of either isotacticity or syndiotacticity. This means that in the carbon-¹³ NMR spectrum of the substantially random interpolymers, the peak areas corresponding to the main chain methylene and methine carbons representing either meso diad sequences or racemic diad sequences should not exceed 75 percent of the total peak area of the main chain methylene and methine carbons. By the subsequently

used term "substantially random interpolmer" it is meant a substantially random interpolmer produced from the above-mentioned monomers.

Suitable α -olefin monomers which are useful for preparing the substantially random ethylene/styrene interpolmer include, for example, α -olefin monomers containing from about 2 to about 20, preferably from about 2 to about 12, more preferably from about 2 to about 8 carbon atoms. Preferred such monomers include ethylene, propylene, butene-1, 4-methyl-1-pentene, hexene-1 and octene-1. Most preferred are ethylene or a combination of ethylene with C_3 - C_8 α -olefins. These α olefins do not contain an aromatic moiety.

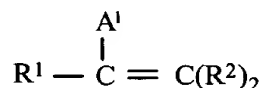
Suitable vinyl or vinylidene aromatic monomers which can be employed to prepare the substantially random ethylene/styrene interpolmer include, for example, those represented by the following formula:



wherein R^1 is selected from the group of radicals consisting of hydrogen and alkyl radicals containing from about 1 to about 4 carbon atoms, preferably hydrogen or methyl; each R^2 is independently selected from the group of radicals consisting of hydrogen and alkyl radicals containing from about 1 to about 4 carbon atoms, preferably hydrogen or methyl; Ar is a phenyl group or a phenyl group substituted with from about 1 to about 5 substituents selected from the group consisting of halo, C_{1-4} -alkyl, and C_{1-4} -haloalkyl; and n has a value from zero to about 4, preferably from zero to about 2, most preferably zero. Particularly suitable such monomers include styrene and lower alkyl- or halogen-substituted derivatives thereof. Exemplary monovinyl or monovinylidene aromatic monomers include styrene, vinyl toluene, α -methylstyrene, t-butyl styrene or chlorostyrene, including all isomers of these compounds. Preferred monomers include styrene, α -methyl styrene, the lower alkyl- (C_1 - C_4) or phenyl-ring substituted derivatives of styrene, such as for example, ortho-, meta-, and para-

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methylstyrene, the ring halogenated styrenes, para-vinyl toluene or mixtures thereof. A more preferred aromatic monovinyl monomer is styrene.

By the term "sterically hindered aliphatic or cycloaliphatic vinyl or vinylidene monomers" in reference to substantially random ethylene/styrene interpolymers, it is meant addition polymerizable vinyl or vinylidene monomers corresponding to the formula:



wherein A¹ is a sterically bulky, aliphatic or cycloaliphatic substituent of up to 20 carbons, R¹ is selected from the group of radicals consisting of hydrogen and alkyl radicals containing from about 1 to about 4 carbon atoms, preferably hydrogen or methyl; each R² is independently selected from the group of radicals consisting of hydrogen and alkyl radicals containing from about 1 to about 4 carbon atoms, preferably hydrogen or methyl; or alternatively R¹ and A¹ together form a ring system.

By the term "sterically bulky" as used in reference to substantially random ethylene/styrene interpolymers it is meant that the monomer bearing this substituent is normally incapable of addition polymerization by standard Ziegler-Natta polymerization catalysts at a rate comparable with ethylene polymerizations.

α-Olefin monomers containing from about 2 to about 20 carbon atoms and having a linear aliphatic structure such as ethylene, propylene, butene-1, hexene-1 and octene-1 are not considered to be sterically hindered aliphatic monomers. With regard to substantially random ethylene/styrene interpolymers, preferred sterically hindered aliphatic or cycloaliphatic vinyl or vinylidene compounds are monomers in which one of the carbon atoms bearing ethylenic unsaturation is tertiary or quaternary substituted. Examples of such substituents include cyclic aliphatic groups such as cyclohexyl, cyclohexenyl, cyclooctenyl, or ring alkyl or aryl substituted derivatives thereof, tert-butyl or norbornyl. Most preferred sterically hindered aliphatic or cycloaliphatic vinyl or vinylidene compounds are the various isomeric vinyl-ring substituted derivatives of

cyclohexene and substituted cyclohexenes, and 5-ethylidene-2-norbornene. Especially suitable are 1-, 3-, and 4-vinylcyclohexene.

The substantially random ethylene/styrene interpolymer usually contains from about 5 to about 65, preferably from about 5 to about 55, more preferably from about 10 to about 50 mole percent of at least one vinyl or vinylidene aromatic monomer; or sterically hindered aliphatic or cycloaliphatic vinyl or vinylidene monomer; or both; and from about 35 to about 95, preferably from about 45 to about 95, more preferably from about 50 to about 90 mole percent of at least one aliphatic α -olefin having from about 2 to about 20 carbon atoms.

Other optional polymerizable ethylenically unsaturated monomer(s) for substantially random ethylene/styrene interpolymers include strained ring olefins such as norbornene and C₁-C₁₀-alkyl or C₆-C₁₀-aryl substituted norbornenes, with an exemplary substantially random interpolymer being ethylene/styrene/norbornene.

A preferred polymeric material for blending with a rigid hydrogenated block copolymer is a polyolefin elastomer or plastomer characterized as having a DSC crystallinity of less than 45 weight percent, preferably less than 30 weight percent, more preferably less than or equal to 20 weight percent, and most preferably less than or equal 16 percent.

The polyolefin elastomer or plastomer will typically be characterized as having a melt index of less than 1000 g/10 minutes, preferably less than 500 g/10 minutes, most preferably less than or equal to 50 g/10 minutes, as determined in accordance with ASTM D-1238, Condition 190°C/2.16 kilogram (kg).

However, in certain embodiments, it will be desirable to utilize an ultra-low molecular weight polyolefin elastomer or plastomer. In particular, ultra-low molecular weight ethylene polymers, such as are disclosed in US-A-6,054,544, may find utility in the practice of the claimed invention.

The ultra-low molecular weight ethylene polymers useful in the practice of the invention will be characterized as having a melt viscosity at 350°F of less than 8200, preferably less than 6000, with melt viscosities at 350°F of less than

600 centipoise being easily attained. The melt viscosity will be chosen based on the desired result. In particular, the lower the melt viscosity of the ultra-low molecular weight ethylene polymer, the more it will tend to reduce the overall viscosity of the compositions of the invention.

5 Melt viscosity is determined in accordance with the following procedure using a Brookfield Laboratories DVII+ Viscometer in disposable aluminum sample chambers. The spindle used is a SC-31 hot-melt spindle, suitable for measuring viscosities in the range of from 10 to 100,000 centipoise. A cutting blade is employed to cut samples into pieces small enough to fit into the 1 inch
10 wide, 5 inches long sample chamber. The sample is placed in the chamber, which is in turn inserted into a Brookfield Thermosel and locked into place with bent needle-nose pliers. The sample chamber has a notch on the bottom that fits the bottom of the Brookfield Thermosel to ensure that the chamber is not allowed to turn when the spindle is inserted and spinning. The sample is heated
15 to 350°F, with additional sample being added until the melted sample is about 1 inch below the top of the sample chamber. The viscometer apparatus is lowered and the spindle submerged into the sample chamber. Lowering is continued until brackets on the viscometer align on the Thermosel. The viscometer is turned on, and set to a shear rate which leads to a torque reading in the range of 30 to 60
20 percent. Readings are taken every minute for about 15 minutes, or until the values stabilize, which final reading is recorded.

When an ultra-low molecular weight ethylene polymer is utilized, it will typically have a density of from 0.850 to 0.970 g/cm³. The density employed will be a function of the end use application contemplated. For instance, when the ultra-low
25 molecular weight ethylene polymer is intended as a wax substitute, densities greater than 0.910, preferably greater than 0.920 g/cm³ will be appropriate. In contrast, when the polymer is intended as to impart some elastomeric characteristics to the composition, densities less than 0.900 g/cm³, preferably less than 0.895 g/cm³ will be appropriate. When the ultra-low molecular weight ethylene polymer is an interpolymers
30 of ethylene and an aromatic comonomer, such as styrene, the density of the

interpolymer will be less than 1.10 g/cm³.

Also, preferably the polymeric material used for blending with the rigid hydrogenated block copolymer is characterized as having a percent permanent set of less than 75 at 23°C, preferably less than or equal 60 at 23°C, more preferably less than or equal to 30 at 23°C and most preferably less than or equal to 15 at 23°C and 38°C and 200 percent strain when measured at a 2 mil thickness using an Instron tensiometer; or preferably a percent set elongation of less than or equal to 25, more preferably 20, most preferably 15 at 23°C and 100 percent strain.

The term "polymer", as used herein, refers to a polymeric compound prepared by polymerizing monomers, whether of the same or a different type. As used herein, generic term "polymer" embraces the terms "homopolymer," "copolymer," "terpolymer" as well as "interpolymer."

The term "interpolymer", as used herein refers to polymers prepared by the polymerization of at least two different types of monomers. As used herein the generic term "interpolymer" includes the term "copolymers" (which is usually employed to refer to polymers prepared from two different monomers) as well as the term "terpolymers" (which is usually employed to refer to polymers prepared from three different types of monomers).

The term "homogeneously branched ethylene polymer" is used herein in the conventional sense to refer to an ethylene interpolymer in which the comonomer is randomly distributed within a given polymer molecule and wherein substantially all of the polymer molecules have the same ethylene to comonomer molar ratio. The term refers to an ethylene interpolymer that are manufactured using so-called homogeneous or single-site catalyst systems known in the art such Ziegler vanadium, hafnium and zirconium catalyst systems and metallocene catalyst systems e.g., a constrained geometry catalyst systems which is further described herein below.

Homogeneously branched ethylene polymers for use in the present invention can be also described as having less than 15 weight percent, preferably less than 10

weight percent, more preferably less than 5 weight percent and most preferably zero (0) weight percent of the polymer with a degree of short chain branching less than or equal to 10 methyls/1000 carbons. That is, the polymer contains no measurable high density polymer fraction (e.g., there is no fraction having a density of equal to or greater than
 5 0.94 g/cm³), as determined, for example, using a temperature rising elution fractionation (TREF) technique and infrared or ¹³C nuclear magnetic resonance (NMR) analysis.

Preferably, the homogeneously branched ethylene polymer is characterized as having a narrow, essentially single melting TREF profile/curve and essentially lacking a
 10 measurable high density polymer portion, as determined using a temperature rising elution fractionation technique (abbreviated herein as "TREF").

The composition distribution of an ethylene interpolymer can be readily determined from TREF as described, for example, by Wild et al., Journal of Polymer Science, Poly. Phys. Ed., Vol. 20, p. 441 (1982), or in U.S. Patent 4,798,081;
 15 5,008,204; or by L. D. Cady, "The Role of Comonomer Type and Distribution in LLDPE Product Performance," SPE Regional Technical Conference, Quaker Square Hilton, Akron, Ohio, October 1-2, pp. 107-119 (1985).

The composition (monomer) distribution of the interpolymer can also be determined using ¹³C NMR analysis in accordance with techniques described in US
 20 Patent No. 5,292,845; U.S. Patent No. 4,798,081; U.S. Patent No. 5,089,321, incorporated here in by reference, and by J. C. Randall, Rev. Macromol. Chem. Phys., C29, pp. 201-317 (1989).

In analytical temperature rising elution fractionation analysis (as described in U.S. Patent No. 4,798,081 and abbreviated herein as "ATREF"), the film or
 25 composition to be analyzed is dissolved in a suitable hot solvent (e.g., trichlorobenzene) and allowed to crystallized in a column containing an inert support (stainless steel shot) by slowly reducing the temperature. The column is equipped with both a refractive index detector and a differential viscometer (DV) detector. An ATREF-DV chromatogram curve is then generated by eluting the crystallized polymer sample from

the column by slowly increasing the temperature of the eluting solvent (trichlorobenzene). The ATREF curve is also frequently called the short chain branching distribution (SCBD) or composition distribution (CD) curve, since it indicates how evenly the comonomer (e.g., octene) is distributed throughout the sample in that as elution temperature decreases, comonomer content increases. The refractive index detector provides the short chain distribution information and the differential viscometer detector provides an estimate of the viscosity average molecular weight. The composition distribution and other compositional information can also be determined using crystallization analysis fractionation such as the CRYSTAF fractional analysis package available commercially from PolymerChar, Valencia, Spain.

Preferred homogeneously branched ethylene polymers (such as, but not limited to, substantially linear ethylene polymers) have a single melting peak between -30 and 150°C, as determined using differential scanning calorimetry (DSC), as opposed to traditional Ziegler polymerized heterogeneously branched ethylene polymers (e.g., LLDPE and ULDPE or VLDPE) which have two or more melting points.

The single melting peak is determined using a differential scanning calorimeter standardized with indium and deionized water. The method involves about 5-7 mg sample sizes, a "first heat" to about 180°C which is held for 4 minutes, a cool down at 10°C/min. to -30°C which is held for 3 minutes, and heat up at 10°C/min. to 150°C to provide a "second heat" heat flow vs. temperature curve from which the melting peak(s) is obtained. Total heat of fusion of the polymer is calculated from the area under the curve.

The homogeneously branched ethylene polymers for use in the invention can be either a substantially linear ethylene polymer or a homogeneously branched linear ethylene polymer.

The term "linear" as used herein means that the ethylene polymer does not have long chain branching. That is, the polymer chains comprising the bulk linear ethylene polymer have an absence of long chain branching, as in the case of traditional linear low density polyethylene polymers or linear high density polyethylene polymers made

using Ziegler polymerization processes (e.g., U.S. 4,076,698 (Anderson et al.)), sometimes called heterogeneous polymers. The term "linear" does not refer to bulk high pressure branched polyethylene, ethylene/vinyl acetate copolymers, or ethylene/vinyl alcohol copolymers which are known to those skilled in the art to have numerous long chain branches.

The term "homogeneously branched linear ethylene polymer" refers to polymers having a narrow short chain branching distribution and an absence of long chain branching. Such "linear" uniformly branched or homogeneous polymers include those made as described in U.S. 3,645,992 (Elston) and those made using so-called single site catalysts in a batch reactor having relatively high ethylene concentrations (as described in U.S. Patent 5,026,798 (Canich) or in U.S. Patent 5,055,438 (Canich)) or those made using constrained geometry catalysts in a batch reactor also having relatively high olefin concentrations (as described in U.S. Patent 5,064,802 (Stevens et al.) or in EP 0 416,815 A2 (Stevens et al.)).

Typically, homogeneously branched linear ethylene polymers are ethylene/ α -olefin interpolymers, wherein the α -olefin is at least one C_3 - C_{20} α -olefin (e.g., propylene, 1-butene, 1-pentene, 4-methyl-1-pentene, 1-hexene, 1-octene and the like) and preferably the at least one C_3 - C_{20} α -olefin is 1-butene, 1-hexene or 1-octene. Most preferably, the ethylene/ α -olefin interpolymers are copolymers of ethylene and a C_3 - C_{20} α -olefin, and especially an ethylene/ C_4 - C_8 α -olefin copolymer such as an ethylene/1-octene copolymer, ethylene/1-butene copolymer, ethylene/1-pentene copolymer or ethylene/1-hexene copolymer.

Suitable homogeneously branched linear ethylene polymers for use in the invention are sold under the designation of TAFMER™ by Mitsui Chemical Corporation and under the designations of EXACT™ and EXCEED™ resins by Exxon Chemical Company.

The term "substantially linear ethylene polymer" as used herein means that the bulk ethylene polymer is substituted, on average, with about 0.01 long chain

branches/1000 total carbons to about 3 long chain branches/1000 total carbons (wherein "total carbons" includes both backbone and branch carbons). Preferred polymers are substituted with about 0.01 long chain branches/1000 total carbons to about 1 long chain branches/1000 total carbons, more preferably from about 0.05 long chain
 5 branches/1000 total carbons to about 1 long chain branched/1000 total carbons, and especially from about 0.3 long chain branches/1000 total carbons to about 1 long chain branches/1000 total carbons.

As used herein, the term "backbone" refers to a discrete molecule, and the term "polymer" or "bulk polymer" refers, in the conventional sense, to the polymer as
 10 formed in a reactor. For the polymer to be a "substantially linear ethylene polymer", the polymer must have at least enough molecules with long chain branching such that the average long chain branching in the bulk polymer is at least an average of from about 0.01/1000 total carbons to about 3 long chain branches/1000 total carbons.

The term "bulk polymer" as used herein means the polymer which results from
 15 the polymerization process as a mixture of polymer molecules and, for substantially linear ethylene polymers, includes molecules having an absence of long chain branching as well as molecules having long chain branching. Thus a "bulk polymer" includes all molecules formed during polymerization. It is understood that, for the substantially linear polymers, not all molecules have long chain branching, but a
 20 sufficient amount do such that the average long chain branching content of the bulk polymer positively affects the melt rheology (i.e., the shear viscosity and melt fracture properties) as described herein below and elsewhere in the literature.

Long chain branching (LCB) is defined herein as a chain length of at least one
 (1) carbon less than the number of carbons in the comonomer, whereas short chain
 25 branching (SCB) is defined herein as a chain length of the same number of carbons in the residue of the comonomer after it is incorporated into the polymer molecule backbone. For example, a substantially linear ethylene/1-octene polymer has backbones with long chain branches of at least seven (7) carbons in length, but it also has short chain branches of only six (6) carbons in length.

Long chain branching can be distinguished from short chain branching by using ^{13}C nuclear magnetic resonance (NMR) spectroscopy and to a limited extent, e.g. for ethylene homopolymers, it can be quantified using the method of Randall, (Rev. Macromol.Chem. Phys., C29 (2&3), p. 285-297 (1989)). However as a practical matter, current ^{13}C nuclear magnetic resonance spectroscopy cannot determine the length of a long chain branch in excess of about six (6) carbon atoms and as such, this analytical technique cannot distinguish between a seven (7) carbon branch and a seventy (70) carbon branch. The long chain branch can be as long as about the same length as the length of the polymer backbone.

Although conventional ^{13}C nuclear magnetic resonance spectroscopy cannot determine the length of a long chain branch in excess of six carbon atoms, there are other known techniques useful for quantifying or determining the presence of long chain branches in ethylene polymers, including ethylene/1-octene interpolymers. For example, U.S. Patent No. 4,500,648, incorporated herein by reference, teaches that long chain branching frequency (LCB) can be represented by the equation $\text{LCB} = b/M_w$ wherein b is the weight average number of long chain branches per molecule and M_w is the weight average molecular weight. The molecular weight averages and the long chain branching characteristics are determined by gel permeation chromatography and intrinsic viscosity methods, respectively.

Two other useful methods for quantifying or determining the presence of long chain branches in ethylene polymers, including ethylene/1-octene interpolymers are gel permeation chromatography coupled with a low angle laser light scattering detector (GPC-LALLS) and gel permeation chromatography coupled with a differential viscometer detector (GPC-DV). The use of these techniques for long chain branch detection and the underlying theories have been well documented in the literature. See, e.g., Zimm, G.H. and Stockmayer, W.H., J. Chem. Phys., 17, 1301 (1949) and Rudin, A., Modern Methods of Polymer Characterization, John Wiley & Sons, New York (1991) pp. 103-112.

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A. Willem deGroot and P. Steve Chum, both of The Dow Chemical Company, at the October 4, 1994 conference of the Federation of Analytical Chemistry and Spectroscopy Society (FACSS) in St. Louis, Missouri, presented data demonstrating that GPC-DV is indeed a useful technique for quantifying the presence of long chain
5 branches in substantially linear ethylene polymers. In particular, deGroot and Chum found that the level of long chain branches in substantially linear ethylene homopolymer samples measured using the Zimm-Stockmayer equation correlated well with the level of long chain branches measured using ^{13}C NMR.

Further, deGroot and Chum found that the presence of octene does not change
10 the hydrodynamic volume of the polyethylene samples in solution and, as such, one can account for the molecular weight increase attributable to octene short chain branches by knowing the mole percent octene in the sample. By deconvoluting the contribution to molecular weight increase attributable to 1-octene short chain branches, deGroot and Chum showed that GPC-DV may be used to quantify the level of long chain branches
15 in substantially linear ethylene/octene copolymers.

DeGroot and Chum also showed that a plot of $\text{Log}(I_2, \text{melt index})$ as a function of $\text{Log}(\text{GPC Weight Average Molecular Weight})$ as determined by GPC-DV illustrates that the long chain branching aspects (but not the extent of long branching) of
substantially linear ethylene polymers are comparable to that of high pressure, highly
20 branched low density polyethylene (LDPE) and are clearly distinct from ethylene polymers produced using Ziegler-type catalysts such as titanium complexes and ordinary homogeneous catalysts such as hafnium and vanadium complexes.

For substantially linear ethylene polymers, the empirical effect of the presence of long chain branching is manifested as enhanced rheological properties which are
25 quantified and expressed in terms of gas extrusion rheometry (GER) results and/or melt flow, I_{10}/I_2 , increases.

The substantially linear ethylene polymers used in the present invention are a unique class of compounds that are further defined in U.S. Patent No. 5,272,236, application number 07/776,130, filed October 15, 1991; U.S. Patent No. 5,278,272,

application number 07/939,281, filed September 2, 1992; and U.S. Patent No. 5,665,800, application number 08/730,766, filed October 16, 1996, each of which is incorporated herein by reference.

Substantially linear ethylene polymers differ significantly from the class of polymers conventionally known as homogeneously branched linear ethylene polymers described above and, for example, by Elston in U.S. Patent 3,645,992. As an important distinction, substantially linear ethylene polymers do not have a linear polymer backbone in the conventional sense of the term "linear" as is the case for homogeneously branched linear ethylene polymers.

Substantially linear ethylene polymers also differ significantly from the class of polymers known conventionally as heterogeneously branched traditional Ziegler polymerized linear ethylene interpolymers (for example, ultra low density polyethylene, linear low density polyethylene or high density polyethylene made, for example, using the technique disclosed by Anderson et al. in U.S. Patent 4,076,698) in that substantially linear ethylene interpolymers are homogeneously branched polymers. Further, substantially linear ethylene polymers also differ from the class of heterogeneously branched ethylene polymers in that substantially linear ethylene polymers are characterized as essentially lacking a measurable high density or crystalline polymer fraction as determined using a temperature rising elution fractionation technique.

The substantially linear ethylene elastomers and plastomers for use in the present invention is characterized as having

- (a) melt flow ratio, $I_{10}/I_2 \geq 5.63$,
- (b) a molecular weight distribution, M_w/M_n , as determined by gel permeation chromatography and defined by the equation:

$$(M_w/M_n) \leq (I_{10}/I_2) - 4.63,$$

- (c) a gas extrusion rheology such that the critical shear rate at onset of surface melt fracture for the substantially linear ethylene polymer is at least 50 percent greater than the critical shear rate at the onset of surface melt fracture for a linear ethylene polymer, wherein the substantially linear ethylene polymer and the linear ethylene polymer comprise the same comonomer or comonomers, the linear ethylene polymer has an I_2 and M_w/M_n within ten percent of the substantially linear ethylene polymer and wherein the respective critical shear rates of the substantially linear ethylene polymer and the linear ethylene polymer are measured at the same melt temperature using a gas extrusion rheometer,
- (d) a single differential scanning calorimetry, DSC, melting peak between -30° and 150°C , and
- (e) a density less than or equal to 0.865 g/cm^3 .

Determination of the critical shear rate and critical shear stress in regards to melt fracture as well as other rheology properties such as "rheological processing index" (PI), is performed using a gas extrusion rheometer (GER). The gas extrusion rheometer is described by M. Shida, R.N. Shroff and L.V. Cancio in Polymer Engineering Science, Vol. 17, No. 11, p. 770 (1977) and in Rheometers for Molten Plastics by John Dealy, published by Van Nostrand Reinhold Co. (1982) on pp. 97-99.

The processing index (PI) is measured at a temperature of 190°C , at nitrogen pressure of 2500 psig (17.2 MPa) using a 0.0296 inch (752 micrometers) diameter (preferably a 0.0143 inch diameter die for high flow polymers, e.g. 50 - 100 I_2 melt index or greater), 20:1 L/D die having an entrance angle of 180° . The GER processing index is calculated in millipoise units from the following equation:

$$PI = 2.15 \times 10^6 \text{ dyne/cm}^2 / (1000 \times \text{shear rate}),$$

where: $2.15 \times 10^6 \text{ dyne/cm}^2$ is the shear stress at 2500 psi (17.2 MPa), and the shear rate is the shear rate at the wall as represented by the following equation:

32 $Q' / (60 \text{ sec/min})(0.745)(\text{Diameter} \times 2.54 \text{ cm/in})^3$, where:

Q' is the extrusion rate (gms/min),

0.745 is the melt density of polyethylene (gm/cm³), and

Diameter is the orifice diameter of the capillary (inches).

5 The PI is the apparent viscosity of a material measured at apparent shear stress of 2.15×10^6 dyne/cm².

For substantially linear ethylene polymers, the PI is less than or equal to 70 percent of that of a conventional linear ethylene polymer having an I_2 , M_w/M_n and density each within ten percent of the substantially linear ethylene polymer.

10 An apparent shear stress vs. apparent shear rate plot is used to identify the melt fracture phenomena over a range of nitrogen pressures from 5250 to 500 psig (36 to 3.4 MPa) using the die or GER test apparatus previously described. According to Ramamurthy in Journal of Rheology, 30(2), 337-357, 1986, above a certain critical flow rate, the observed extrudate irregularities may be broadly classified into two main types:
15 surface melt fracture and gross melt fracture.

Surface melt fracture occurs under apparently steady flow conditions and ranges in detail from loss of specular gloss to the more severe form of "sharkskin". In this disclosure, the onset of surface melt fracture is characterized at the beginning of losing extrudate gloss at which the surface roughness of extrudate can only be detected by 40x
20 magnification. The critical shear rate at onset of surface melt fracture for the substantially linear ethylene polymers is at least 50 percent greater than the critical shear rate at the onset of surface melt fracture of a linear ethylene polymer having about the same I_2 and M_w/M_n . Preferably, the critical shear stress at onset of surface melt fracture for the substantially linear ethylene polymers of the invention is greater than
25 about 2.8×10^6 dyne/cm².

Gross melt fracture occurs at unsteady flow conditions and ranges in detail from regular (alternating rough and smooth, helical, etc.) to random distortions. For commercial acceptability, (e.g., in blown film products), surface defects should be minimal, if not absent. The critical shear rate at onset of surface melt fracture (OSMF) and critical shear stress at onset of gross melt fracture (OGMF) will be used herein based on the changes of surface roughness and configurations of the extrudates extruded by a GER. For the substantially linear ethylene polymers used in the invention, the critical shear stress at onset of gross melt fracture is preferably greater than about 4×10^6 dyne/cm².

For the processing index determination and for the GER melt fracture determination, substantially linear ethylene polymers are tested without inorganic fillers and do not have more than 20 ppm (parts per million) aluminum catalyst residue. Preferably, however, for the processing index and melt fracture tests, substantially linear ethylene polymers do contain antioxidants such as phenols, hindered phenols, phosphites or phosphonites, preferably a combination of a phenol or hindered phenol and a phosphite or a phosphonite.

The molecular weights and molecular weight distributions are determined by gel permeation chromatography (GPC). A suitable unit is a Waters 150C high temperature chromatographic unit equipped with a differential refractometer and three columns of mixed porosity where columns are supplied by Polymer Laboratories and are commonly packed with pore sizes of 10^3 , 10^4 , 10^5 and 10^6 Å. For ethylene polymers, the unit operating temperature is about 140°C and the solvent is 1,2,4-trichlorobenzene, from which about 0.3 percent by weight solutions of the samples are prepared for injection. Conversely, for the rigid hydrogenated block copolymers, the unit operating temperature is about 25°C and tetrahydrofuran is used as the solvent. A suitable flow rate is about 1.0 milliliters/minute and the injection size is typically about 100 microliters.

For the ethylene polymers where used in the present invention, the molecular weight determination with respect to the polymer backbone is deduced by using narrow

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molecular weight distribution polystyrene standards (from Polymer Laboratories) in conjunction with their elution volumes. The equivalent polyethylene molecular weights are determined by using appropriate Mark-Houwink coefficients for polyethylene and polystyrene (as described by Williams and Ward in Journal of Polymer Science, 5 Polymer Letters, Vol. 6, p. 621, 1968) to derive the following equation:

$$M_{\text{polyethylene}} = a * (M_{\text{polystyrene}})^b.$$

In this equation, $a = 0.4316$ and $b = 1.0$. Weight average molecular weight, M_w , is calculated in the usual manner according to the following formula: $M_j = (\sum w_i (M_i^j))^j$.

Where w_i is the weight fraction of the molecules with molecular weight M_i eluting from the GPC column in fraction i and $j = 1$ when calculating M_w and $j = -1$ when calculating M_n . 10

For the at least one homogeneously branched ethylene polymer used in the present invention, the M_w/M_n is preferably less than 3.5, more preferably less than 3.0, most preferably less than 2.5, and especially in the range of from about 1.5 to about 2.5 and most especially in the range from about 1.8 to about 2.3. 15

Substantially linear ethylene polymers are known to have excellent processability, despite having a relatively narrow molecular weight distribution (that is, the M_w/M_n ratio is typically less than about 3.5). Surprisingly, unlike homogeneously and heterogeneously branched linear ethylene polymers, the melt flow ratio (I_{10}/I_2) of substantially linear ethylene polymers can be varied essentially independently of the molecular weight distribution, M_w/M_n . Accordingly, especially when good extrusion processability is desired, the preferred ethylene polymer for use in the present invention is a homogeneously branched substantially linear ethylene interpolymer. 20

Suitable constrained geometry catalysts for use manufacturing substantially linear ethylene polymers include constrained geometry catalysts as disclosed in U.S. application number 07/545,403, filed July 3, 1990; U.S. application number 07/758,654, filed September 12, 1991; U.S. Patent No. 5,132,380 (application number 07/758,654); U.S. Patent No. 5,064,802 (application number 07/547,728); U.S. 25

Patent No. 5,470,993 (application number 08/241,523); U.S. Patent No. 5,453,410 (application number 08/108,693); U.S. Patent No. 5,374,696 (application number 08/08,003); U.S. Patent No. 5,532,394 (application number 08/295,768); U.S. Patent No. 5,494,874 (application number 08/294,469); and U.S. Patent No. 5,189,192 (application number 07/647,111), the teachings of all of which are incorporated herein by reference.

Suitable catalyst complexes may also be prepared according to the teachings of WO 93/08199, and the patents issuing therefrom, all of which are incorporated herein by reference. Further, the monocyclopentadienyl transition metal olefin polymerization catalysts taught in U.S. 5,026,798, which is incorporated herein by reference, are also believed to be suitable for use in preparing the polymers of the present invention, so long as the polymerization conditions substantially conform to those described in U.S. Patent No. 5,272,236; U.S. Patent No. 5,278,272 and U.S. Patent No. 5,665,800, especially with strict attention to the requirement of continuous polymerization. Such polymerization methods are also described in PCT/U.S. 92/08812 (filed October 15, 1992).

The foregoing catalysts may be further described as comprising a metal coordination complex comprising a metal of groups 3-10 or the Lanthanide series of the Periodic Table of the Elements and a delocalize β -bonded moiety substituted with a constrain-inducing moiety, said complex having a constrained geometry about the metal atom such that the angle at the metal between the centroid of the delocalized, substituted pi-bonded moiety and the center of at least one remaining substituent is less than such angle in a similar complex containing a similar pi-bonded moiety lacking in such constrain-inducing substituent, and provided further that for such complexes comprising more than one delocalized, substituted pi-bonded moiety, only one thereof for each metal atom of the complex is a cyclic, delocalized, substituted pi-bonded moiety. The catalyst further comprises an activating cocatalyst.

Suitable cocatalysts for use herein include polymeric or oligomeric aluminoxanes, especially methyl aluminoxane, as well as inert, compatible,

noncoordinating, ion forming compounds. So-called modified methyl aluminoxane (MMAO) is also suitable for use as a cocatalyst. One technique for preparing such modified aluminoxane is disclosed in U.S. Patent No. 5,041,584, the disclosure of which is incorporated herein by reference. Aluminoxanes can also be made as
5 disclosed in U.S. Patent No. 5,218,071; U.S. Patent No. 5,086,024; U.S. Patent No. 5,041,585; U.S. Patent No. 5,041,583; U.S. Patent No. 5,015,749; U.S. Patent No. 4,960,878; and U.S. Patent No. 4,544,762, the disclosures of all of which are incorporated herein by reference.

Aluminoxanes, including modified methyl aluminoxanes, when used in the
10 polymerization, are preferably used such that the catalyst residue remaining in the (finished) polymer is preferably in the range of from about 0 to about 20 ppm aluminum, especially from about 0 to about 10 ppm aluminum, and more preferably from about 0 to about 5 ppm aluminum. In order to measure the bulk polymer properties (e.g. PI or melt fracture), aqueous HCl is used to extract the aluminoxane
15 from the polymer. Preferred cocatalysts, however, are inert, noncoordinating, boron compounds such as those described in EP 520732.

Substantially linear ethylene are produced via a continuous (as opposed to a batch) controlled polymerization process using at least one reactor (e.g., as disclosed in WO 93/07187, WO 93/07188, and WO 93/07189), but can also be produced using
20 multiple reactors (e.g., using a multiple reactor configuration as described in U.S. Patent No. 3,914,342, the disclosure of which is incorporated herein by reference) at a polymerization temperature and pressure sufficient to produce the interpolymers having the desired properties. The multiple reactors can be operated in series or in parallel, with at least one constrained geometry catalyst employed in at least one of the reactors.

Substantially linear ethylene polymers can be prepared via the continuous
25 solution, slurry, or gas phase polymerization in the presence of a constrained geometry catalyst, such as the method disclosed in EP 416,815-A. The polymerization can generally be performed in any reactor system known in the art including, but not limited to, a tank reactor(s), a sphere reactor(s), a recycling loop reactor(s) or combinations

thereof and the like, any reactor or all reactors operated partially or completely adiabatically, nonadiabatically or a combination of both and the like. Preferably, a continuous loop-reactor solution polymerization process is used to manufacture the substantially linear ethylene polymer used in the present invention.

5 In general, the continuous polymerization required to manufacture substantially linear ethylene polymers may be accomplished at conditions well known in the prior art for Ziegler-Natta or Kaminsky-Sinn type polymerization reactions, that is, temperatures from 0 to 250°C and pressures from atmospheric to 1000 atmospheres (100 MPa). Suspension, solution, slurry, gas phase or other process conditions may be employed if
10 desired.

A support may be employed in the polymerization, but preferably the catalysts are used in a homogeneous (i.e., soluble) manner. It will, of course, be appreciated that the active catalyst system forms *in situ* if the catalyst and the cocatalyst components thereof are added directly to the polymerization process and a suitable solvent or
15 diluent, including condensed monomer, is used in said polymerization process. It is, however, preferred to form the active catalyst in a separate step in a suitable solvent prior to adding the same to the polymerization mixture.

The substantially linear ethylene polymers used in the present invention are interpolymers of ethylene with at least one C₃-C₂₀ α -olefin and/or C₄-C₁₈ diolefin.
20 Copolymers of ethylene and an α -olefin of C₃-C₂₀ carbon atoms are especially preferred. The term "interpolymer" as discussed above is used herein to indicate a copolymer, or a terpolymer, or the like, where, at least one other comonomer is polymerized with ethylene or propylene to make the interpolymer.

Suitable unsaturated comonomers useful for polymerizing with ethylene
25 include, for example, ethylenically unsaturated monomers, conjugated or non-conjugated dienes, polyenes, etc. Examples of such comonomers include C₃-C₂₀ α -olefins such as propylene, isobutylene, 1-butene, 1-hexene, 1-pentene, 4-methyl-1-pentene, 1-heptene, 1-octene, 1-nonene, 1-decene, and the like. Preferred comonomers include propylene, 1-butene, 1-pentene, 1-hexene, 4-methyl-1-pentene, 1-heptene, and

1-octene, and 1-octene is especially preferred. Other suitable monomers include styrene, halo- or alkyl-substituted styrenes, vinylbenzocyclobutane, 1,4-hexadiene, 1,7-octadiene, and naphthenics (e.g., cyclopentene, cyclohexene and cyclooctene).

In one embodiment, the composition used in the present invention comprises at least one rigid hydrogenated block copolymer and at least one polypropylene polymer. Suitable polypropylene polymers for use in the invention, including random block propylene ethylene polymers, are available from a number of manufacturers, such as, for example, Montell Polyolefins and Exxon Chemical Company. At Exxon, suitable polypropylene polymers are supplied under the designations ESCORENE™ and
10 ACHIEVE™.

Suitable poly lactic acid (PLA) polymers for use in the invention are well known in the literature (e.g., see D. M. Bigg et al., "Effect of Copolymer Ratio on the Crystallinity and Properties of Polylactic Acid Copolymers", ANTEC '96, pp. 2028-2039; WO 90/01521; EP 0 515203A; and EP 0 748846A2). Suitable poly lactic acid
15 polymers are supplied commercially by Cargill Dow under the designation EcoPLA™.

Suitable thermoplastic polyurethane polymers for use in the invention are commercially available from The Dow Chemical Company under the designation PELLATHANE™.

Suitable polyolefin carbon monoxide interpolymers can be manufactured using well known high pressure free-radical polymerization methods. However, they may also be manufactured using traditional Ziegler-Natta catalysis and even with the use of so-called homogeneous catalyst systems such as those described and referenced herein above.

Suitable free-radical initiated high pressure carbonyl-containing ethylene polymers such as ethylene acrylic acid interpolymers can be manufactured by any
25 technique known in the art including the methods taught by Thomson and Waples in U.S. Patent No. 3,520,861 and by McKinney et al. in U.S. Nos. 4,988,781; 4,599,392; and 5,384,373, the disclosures of which are incorporated herein by reference.

Suitable ethylene vinyl acetate interpolymers for use in the invention are commercially available from various suppliers, including Exxon Chemical Company and E.I. du Pont de Nemours and Company.

5 Suitable ethylene/alkyl acrylate interpolymers are commercially available from various suppliers. Suitable ethylene/acrylic acid interpolymers are commercially available from The Dow Chemical Company under the designation PRIMACOR™. Suitable ethylene/methacrylic acid interpolymers are commercially available from E.I. du Pont de Nemours and Company under the designation NUCREL™.

10 Suitable polyethylene terephthalate polymers include LIGHTER™ available from The Dow Chemical Company.

15 Chlorinated polyethylene (CPE), especially chlorinated substantially linear ethylene polymers, can be prepared by chlorinating polyethylene in accordance with well known techniques. Preferably, chlorinated polyethylene comprises equal to or greater than 30 weight percent chlorine. Suitable chlorinated polyethylenes for use in the invention are commercially supplied by Dupont Dow Elastomers L.L.C under the designation TYRIN®.

Suitable polycarbonates are commercially available from various suppliers, including The Dow Chemical Company under the designation CALIBRE®.

20 Suitable polyamids, such as nylon are commercially available from various suppliers, including ZYTEL™ available from DuPont, CAPRON™ available from Allied and ULTAMID™ available from BASF.

Suitable polyethers are commercially available from various suppliers, including ULTEM™ available from GE Plastics.

25 Suitable poly/vinyl chloride polymers are commercially available from various suppliers, including ALPHA DURAL™ AND ALPHA available from Alpha Chemical and Plastics, UNICHEM™ available from Colorite Plastics, GEON™ available from B.F. Goodrich.

Suitable poly/vinylidene chloride polymers are commercially available from various suppliers, including SARAN™ available from The Dow Chemical Company.

Suitable polyesters are commercially available from various suppliers, including FIBERCORE™ available from American Cyanamid; AROPOL™ available from
5 Ashland Chemical Company and COREZYN™ available from Interplastic.

Suitable non-hydrogenated styrene-butadiene block copolymers are commercially available from various suppliers, including Dexco under the designation Vector™. Additionally, partially hydrogenated block copolymers can also be used and are well known in the art. Such polymers are easily prepared using hydrogenation
10 catalysts well known in the art. Partially hydrogenated block copolymers include block copolymers having up to 100 percent diene unsaturation and 0 to less than 90 percent aromatic hydrogenation.

Suitable styrenic polymers include syndiotactic and atactic polystyrenes and high impact polystyrene resins which are commercially available from various
15 suppliers, including QUESTRA®, STYRON® and STYRON-A-TECH®. available from The Dow Chemical Company .

Suitable ABS resins are commercially available from various suppliers, including MAGNUM® available from The Dow Chemical Company .

Suitable ABS/PC compositions are commercially available from various
20 suppliers, including PULSE® available from The Dow Chemical Company .

Suitable SAN copolymers are commercially available from various suppliers, including TYRIL® available from The Dow Chemical Company .

Suitable ethylene vinyl alcohol copolymers are commercially available from various suppliers, including-ELVANOL™ which is available from DuPont and EVA
25 polymers available from Eval Company of America.

Suitable epoxy resins are commercially available from various suppliers, including D.E.R. resins and D.E.N. resins available from The Dow Chemical Company.

Suitable cyclic-olefin-polymers and copolymers are polymerized cycloolefin monomers exemplified by norbornene-type polymers such as are described in U.S.

- 5 5,115,041, 5,142,007, 5,143,979, all of which are incorporated herein by reference. The cycloolefin moiety may be substituted or unsubstituted. Suitable cycloolefin monomers include substituted and unsubstituted norbornenes, dicyclopentadienes, dihydrodicyclopentadienes, trimers of cyclopentadiene, tetracyclododecenes, hexacycloheptadecenes, ethylidenyl norbornenes and vinylnorbornenes. Substituents
- 10 on the cycloolefin monomers include hydrogen, alkyl alkenyl, and aryl groups of 1 to 20 carbon atoms and saturated and unsaturated cyclic groups of 3 to 12 carbon atoms which can be formed with one or more, preferably two, ring carbon atoms. The substituents on the cycloolefin monomers can be any which do not poison or deactivate the polymerization catalyst. Examples of preferred monomers include but are not
- 15 limited to dicyclopentadiene, methyltetracyclo-dodecene, 2-norbornene, and other norbornene monomers such as 5-methyl-2-norbornene, 5,6-dimethyl-2-norbornene, 5-ethyl-2-norbornene, 5-ethylidenyl-2-norbornene, 5-butyl-2-norbornene, 5-hexyl-2-norbornene, 5-octyl-2-norbornene, 5-phenyl-2-norbornene, 5-dodecyl-2-norbornene, 5-isobutyl-2-norbornene, 5-octadecyl-2-norbornene, 5-isopropyl-2-norbornene, 5-p-
- 20 toluyl-2-norbornene, 5- α -naphthyl-2-norbornene, 5-cyclohexyl-2-norbornene, 5-isopropenyl-2-norbornene, 5-vinyl-2-norbornene, 5,5-dimethyl-2-norbornene, tricyclopentadiene (or cyclopentadiene trimer), tetracyclopentadiene (or cyclopentadiene tetramer), dihydrodicyclopentadiene (or cyclopentene-cyclopentadiene co-dimer), methyl-cyclopentadiene dimer, ethyl-cyclopentadiene dimer,
- 25 tetracyclododecene 9-methyl-tetracyclo[6,2,1,13,6O2,7]dodecene-4, (or methyl-tetracyclododecene), 9-ethyl-tetracyclo[6,2,1,13,6O2,7]dodecene-4, (or ethyl-tetracyclododecene), 9-hexyl-tetracyclo-[6,2,1,13,6O2,7]dodecene-4, 9-decyl-tetracyclo[6,2,1,13,6O2,7]dodecene-4, 9-decyl-tetracyclo[6,2,1,13,6O2,7]dodecene-4, 9,10-dimethyl-tetracyclo[6,2,1,13,6O2,7]dodecene-4, 9-methyl-10-ethyl-
- 30 tetracyclo[6,2,1,13,6O2,7]dodecene-4, 9-cyclohexyl-tetracyclo

[6,2,1,13,6O2,7]dodecene-4, 9-chloro-tetracyclo[6,2,1,13,6O2,7]dodecene-4, 9-bromo-tetracyclo[6,2,1,13,6O2,7]-dodecene-4, 9-fluoro-tetracyclo[6,2,1,13,6O2,7]dodecene-4, 9-isobutyl-tetracyclo-[6,2,1,13,6O2,7]dodecene-4, and 9,10-dichlorotetracyclo[6,2,1,13,6O2,7]-dodecene-4.

5 Polymers comprising two or more different types of cyclic olefin monomeric units are also suitable. For example, copolymers of methyltetracyclododecane (MTD) and methylnorbornene (MNB) are especially suitable. More preferably, the polymers comprise three or more different types of monomeric unites, e.g., terpolymers, including MTD, MNB and dicyclopentadiene (DCPD).

10 Additionally, hydrogenated vinyl aromatic homopolymers can be used in combination with the hydrogenated block copolymers. Hydrogenated vinyl aromatic homopolymers typically have high aromatic hydrogenation levels as well (greater than 80, preferably greater than 90 percent). Other hydrogenated vinyl aromatic/conjugated diene block copolymers can also be used, provided that it is a different polymer than the
15 hydrogenated block copolymer selected in I).

Any polymeric material which will enhance the properties of a hydrogenated block copolymer or be enhanced by the presence of a hydrogenated block copolymer is useful in the compositions utilized in the present invention.

Optionally, compatibilizers may also be used in the composition of the present
20 invention. A compatibilizer typically contains a functional group which is compatible with the hydrogenated block copolymer and an additional functional group which is compatible with the other synthetic or natural polymer. Compatibilizers are well known in the art and one skilled in the art would easily be able to recognize the type of compatibilizer suitable for the desired compositions, if needed. For example, a blend of
25 a hydrogenated rigid block copolymer with a styrene-butadiene-styrene block copolymer or other styrenic polymer may additionally comprise a styrene-ethylenebutene-styrene block copolymer as a compatibilizer. Additionally, a blend of a hydrogenated rigid block copolymer with a polycarbonate may additionally comprise a polyamide-maleic anhydride grafted polyethylene as a compatibilizer

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The polymer blend compositions used in the present invention typically contain from 0.5, generally from 1, preferably from 3, more preferably from 5 and most preferably from 10 to 99.5, generally to 99, preferably to 97, more preferably to 95 and most preferably to 90 weight percent of the rigid hydrogenated block copolymer based on the total weight of the composition.

In one embodiment, the additional polymer comprises from 5, typically from 10, generally from 15, preferably from 25, more preferably from 30 and most preferably from 40 to 95, typically to 90, generally to 85, preferably to 75, more preferably to 70 and most preferably to 60 weight percent of the composition comprising the hydrogenated rigid block copolymer.

In one embodiment of the present invention, the composition comprises more than one hydrogenated block copolymer. The composition may comprise a flexible hydrogenated block copolymer or another rigid hydrogenated block copolymer. A flexible hydrogenated block copolymer is defined as having at least two distinct blocks of hydrogenated polymerized vinyl aromatic monomer, herein referred to as hydrogenated vinyl aromatic polymer blocks, and at least one block of hydrogenated polymerized conjugated diene monomer, herein referred to as hydrogenated conjugated diene polymer block, and is further characterized by:

a) a weight ratio of hydrogenated conjugated diene polymer block to hydrogenated vinyl aromatic polymer block of greater than 40:60;

b) a total number average molecular weight (M_n) of from 30,000 to 150,000, wherein each hydrogenated vinyl aromatic polymer block (A) has a M_{n_a} of from 5,000 to 45,000 and each hydrogenated conjugated diene polymer block (B) has a M_{n_b} of from 12,000 to 110,000; and

c) a hydrogenation level such that each hydrogenated vinyl aromatic polymer block has a hydrogenation level of greater than 90 percent and each hydrogenated conjugated diene polymer block has a hydrogenation level of greater than 95 percent.

The compositions of rigid hydrogenated block copolymer and additional polymeric material may be prepared by any suitable means known in the art such as, but not limited to, dry blending in a pelletized form in the desired proportions followed by melt blending in a screw extruder, Banbury mixer or the like. The dry blended pellets
5 may be directly melt processed into a final solid state article by, for example, injection molding. Additionally, the compositions may be prepared by solution mixing the individual polymeric components.

Additives such as antioxidants (for example, hindered phenols such as, for example, Irganox® 1010), phosphites (for example, Irgafos® 168)), U. V. stabilizers,
10 cling additives (for example, polyisobutylene), antiblock additives, slip agents, colorants, pigments, fillers, fire retardants, light and heat stabilizers, extension oils and the like can also be included in the compositions of the present invention, to the extent that they do not interfere with the enhanced properties discovered by applicants. In-process additives, e.g. calcium stearate, water, and fluoropolymers may also be used for
15 purposes such as for the deactivation of residual catalyst or for further improved processability.

In another aspect of the present invention, rigid hydrogenated block copolymers, or blends thereof can also be used in the form of aqueous dispersions for use in coatings and dipped articles. Such dispersions will comprised the hydrogenated rigid block
20 copolymer, optional blended polymers, water and surfactant(s). Such dispersions can be produced using conventional batch or continuous processes such as phase inversion or direct dispersion techniques, known to those skilled in the art.

Additionally, high internal phase ratio (HIPR) emulsions, as described in U.S. 5,539,021, incorporated herein by reference, can be produced by continuously merging
25 into a disperser, in the presence of an emulsifying and a stabilizing amount of a surfactant, a continuous phase liquid stream having a flow rate R1, and a disperse phase liquid stream having a flow rate R2; mixing the merged streams with a sufficient amount of shear, with R2:R1 sufficiently constant, to form the HIPR emulsion without phase inversion or stepwise distribution of an internal phase into an external phase;

wherein R2:R1 is in a range where the polydispersity of the high internal phase ratio emulsion is less than 2.

The continuous phase and disperse phase liquid streams are sufficiently immiscible with each other to be emulsifiable. In one aspect R2:R1 is defined by a range where the polydispersity of the particles of the HIPR emulsion is less than 2. The term polydispersity is used to denote the ratio of the volume average diameter and the number average diameter of the particles, or D_v/D_n .

Preferably R2:R1 is such that the polydispersity is less than 1.5, more preferably less than 1.2, and most preferably not greater than 1.1. The allowable variance of the rates of each stream depends, in part, on the nature of the disperse and continuous phases, and the dispersers used to make the HIPR emulsion. Preferably this variance is not greater than 10, more preferably not greater than 5, and most preferably less than 1 percent. Preferably, the average particle size of the HIPR emulsion is less than about 2 microns, more preferably, less than 1 micron.

The continuous phase and the disperse phase are liquids that are sufficiently immiscible to form a stable emulsion in the presence of a sufficient quantity of a surfactant. The liquid may be neat, molten, or a solid or unpumpable liquid dissolved in a solvent.

Preferably, the continuous phase is aqueous and the disperse phase comprises the hydrogenated rigid block copolymer, and optionally a solvent. Suitable solvents include those used in the production of the hydrogenated block copolymer as taught herein.

Suitable surfactants include anionic, cationic, nonionic, or combinations thereof. Generally, higher surfactant concentrations result in smaller diameter particles, but surfactant concentrations that are too high tend to deleteriously affect the properties of the final product made from the emulsion. Typically surfactant concentrations are in the range of 0.1, more preferably 0.5, and most preferably 2, to about 15, preferably to about 8, more preferably to about 6 and most preferably about 4 weight percent, based

on the weight of the dispersed polymer. The surfactant may be added initially to either the continuous phase or the disperse phase prior to mixing of the two phases, or added separately to the mixing device as a third stream. The surfactant is preferably added initially with the disperse phase prior to mixing of the two phases.

5 Of particular interest are the class of surfactants comprising the alkali or amine fatty acid salts such as alkali metal oleates (sodium oleate) and stearates; polyoxyethylene nonionics; alkali metal lauryl sulfates, quaternary ammonium surfactants; alkali metal alkylbenzene sulfonates, such as sodium dodecylbenzene sulfonate; and alkali metal soaps of modified resins.

10 Typically the dispersion produced contains a concentration of dispersed phase in amounts up to about 60 percent solids in order to have viscosities that are reasonable for processing. Continuous processes, such as in U.S. 5,539,021 will produce higher solids concentrations, but are typically diluted before use.

15 Examples of continuous processes suitable for the formation of these aqueous dispersions include U.S. 4,123,403; U.S. 5,539,021 and U.S. 5,688,842, all of which are incorporated herein by reference.

20 A latex is prepared from an HIPR emulsion by combining the emulsion with a suitable amount of the liquid which constitutes the continuous phase liquid, or a liquid which is compatible with the continuous phase, but which does not interfere with the integrity of the particles. Where water is the continuous phase, the latex is prepared by adding water to the HIPR emulsion. More preferably, the latex is made in a continuous fashion by directing the HIPR emulsion and water through any suitable dilution unit, such as a centrifugal pump-head.

25 Rigid hydrogenated block copolymer compositions have various advantages including excellent impact properties and chemical resistance. The following end-use applications advantageously utilize such rigid hydrogenated block copolymers and blends thereof.

One aspect of the present invention is related to films produced from a composition comprising a rigid hydrogenated block copolymer. The films can be monolayer or multilayer films as well as uniaxial, biaxial and multiaxial oriented films. The film typically has a thickness of less than 20 mils. Such films include, but are not limited to, cast films such as capacitor films, key pads, uniaxially oriented film, weatherable film, labels, release liners, envelope window film, box/carton window film, medical packaging film, film sheet, trays, graphic art films, membrane switches, blister packaging for food and pharmaceuticals and UV protection films, blown films such as biaxially oriented films and solvent cast films.

Methods of producing films from polymeric materials are well known in the art and described in Plastics Engineering Handbook of the Society of the Plastics Industry, Inc., Fourth Edition, 1976, pages 156, 174, 180 and 183.

Another aspect of the present invention is related to sheet produced from a composition comprising a rigid hydrogenated block copolymer. Sheet typically has a thickness of 20 mils or more. Rigid hydrogenated block copolymer sheet can be used to produce products which include, but are not limited to, automotive glazing, architectural glazing, point of purchase displays, machine guards, ceiling light panels, solar collectors, flat panel displays, basketball backboards, wind screens, bug deflectors, sun roofs, signage, protective sheet (such as boards used in hockey rinks), and the like. Additionally, sheet can be thermoformed to produce articles such as containers and the like.

Methods of producing sheet from polymeric materials are well known in the art and include extrusion, and calendering, all of which are described in Plastics Engineering Handbook of the Society of the Plastics Industry, Inc., Fourth Edition, 1976, on pages 183, 348, and 357.

Additional applications of film and sheet include microwaveable sheet and packaging, thermoformed cups/containers, sunroofs, containers and trays for food, liquid crystal display substrates, rear projection TV screens, beverage machine covers, labels, architectural and greenhouse glazing, bug deflectors and side wind screens,

microwave or appliance doors, coatings, films or protective cap layers for improved surface hardness, scratch or abrasion resistance, surface luster and transparency; graphic arts film, laser-readable parcel window film, index tabs, pharmaceutical packaging, solar cell covers, heat sealable films, photosensitive films, weatherable film or sheet, electrical and capacitor films, transparency films, barrier films, window films, steam sterilization film, recreational vehicle exteriors, boat/marine exterior components such as transparent hatches, camper tops and outdoor signage.

The films and sheet may be monolayer or multilayer in structure. Additional layers may be other polymeric materials including, but not limited to those polymers listed as possible polymers for blending with the rigid hydrogenated block copolymers.

Another aspect of the present invention is related to extruded profiles produced from a composition comprising a rigid hydrogenated block copolymer. Such profiles include, but are not limited to, window blinds and wand profiles, roofing products, exterior trim, window trim, tubing, pipe, rods, fluorescent light tubes, packaging, plastic lumber and the like.

Methods of producing profiles from polymeric materials are well known in the art and described in Plastics Engineering Handbook of the Society of the Plastics Industry, Inc., Fourth Edition, 1976, page 191.

Another aspect of the present invention is related to fibers produced from a composition comprising a rigid hydrogenated block copolymers. Such fibers include, but are not limited to, electronic optic fibers, fiber glass applications, fiber reinforcement, filter media, textiles, nonwovens, yarns and the like.

Methods of producing fibers from polymeric materials are well known in the art and include spunbond fibers or melt blown fibers as disclosed in U.S. Patents 4,340,563; 4,663,220; 4,668,566; or 4,322,027, gel spun fibers disclosed in U.S. Patent No. 4,413,110, and fabrics produced therefrom which is disclosed in U.S. 3,485,706, all of which are incorporated herein by reference.

Another aspect of the present invention is related to coated articles produced from a composition comprising a rigid hydrogenated block copolymer. Coated articles include extrusion coated articles and aqueous dispersion coated articles, coated fabric, coated inorganic materials such as concrete, glass and the like, coated paper or cardboard, coated wood products, and coated metal products. Examples include carpet backing, awnings, shading fabric, indoor and outdoor sun screens, wall coverings, food packaging, microporous waterproof wovens, tent fabrics, and caravan extensions, garden furniture garments, safety and protective wovens, films, fibers, apparel, bandages, and the like. Additionally, the rigid hydrogenated block copolymers can also be used in paint formulations. Alternatively, coating products can be produced using a spin coating process, wherein the rigid hydrogenated block copolymer is spin coated onto a mold to produce an article; such as spin coating an optical media disc or spin coating onto an optical media disc. Additionally, dipped products can also be made using coatings of the hydrogenated block copolymer. In particular, dipped goods can be produced using aqueous dispersions of the hydrogenated block copolymer or blends thereof.

Methods of coating with polymeric materials are well known in the art and include extrusion, solvent casting, and coating from aqueous dispersion/emulsions, all of which are described in Plastics Engineering Handbook of the Society of the Plastics Industry, Inc., Fourth Edition, 1976, on pages 185, and spin coating as described in U.S. Patents 5,635,114; 5,468,324; and 5,663,016, which are incorporated herein by reference.

Another aspect of the present invention is related to injection molded articles produced from a composition comprising a rigid hydrogenated block copolymer. Injection molded articles include, but are not limited to, refrigerator shelving and crisper drawers, blenders, lenses for automotive applications such as headlamps and instrument panels, reusable flatware, tumblers, pitchers, toothbrush and hairbrush handles, tool handles, housewares, industrial lighting lenses such as HID (high intensity discharge), fluorescent and incandescent lenses, medical labware, syringes, optical devices such as industrial and ophthalmic precision lenses, light guides, prisms, lenses,

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laser printer lenses, transparent cover for outdoor instruments and gages, optical mirrors, optical lenses, diffraction lenses, optical filters, CD pickup lenses, laser waveguides, camera lenses, contact lenses, commercial/residential/industrial lenses, labware, test tubes, pipettes, syringes, catheters, flasks, beakers, sterilization containers, pharmaceutical packaging, optical fiber connectors, auto interior and exterior lenses including center high mount stop-lamps, dome lights, courtesy lamp lenses, light distribution systems and the like.

Methods of injection molding with polymeric materials are well known in the art and are described in Plastics Engineering Handbook of the Society of the Plastics Industry, Inc., Fourth Edition, 1976, on page 83.

Another aspect of the present invention is related to rotational molded articles, which include large articles such as toys (hobbyhorses, dolls, sandboxes, small swimming pools, and athletic balls), containers, light globes, storage tanks, furniture, carboys, bottles, shipping containers, business and recreational furniture, planters, trash containers, whirlpool tubs, light globes, boats, canoes, camper tops, advertising display signs, racks, mannequins and the like.

Methods of rotational molding and rotational/slush molding are described in Plastics Engineering Handbook of the Society of the Plastics Industry, Inc., Fourth Edition, 1976, page 348.

Another aspect of the present invention is related to blow molded articles produced from a composition comprising a rigid hydrogenated block copolymer. Blow molded articles include, but are not limited to, extruded bottles, injection molding bottles such as baby bottles and medical use bottles, water tanks, air ducts, hollow industrial parts, seat backs, fluid reservoirs, stadium seating, structural covers for office equipment, and the like.

Methods of blow molding with polymeric materials are well known in the art and are described in Plastics Engineering Handbook of the Society of the Plastics Industry, Inc., Fourth Edition, 1976, on page 326.

Another aspect of the present invention is related to pultruded articles produced from a composition comprising a rigid hydrogenated block copolymer. Pultruded articles are continuous, cross-sectional, composite, extruded profiles produced by extruding a polymer melt and continuous fiber, simultaneously, through the same profile die. structural beams, reinforcement bar, barricades, composite pipe, automotive bumper moldings, concrete reinforcement, window/door lineals, wood reinforcement, glulam (laminated joists) and the like.

Methods of pultrusion with polymeric materials are well known in the art and are described in Plastics Engineering Handbook of the Society of the Plastics Industry, Inc., Fourth Edition, 1976, on page 47.

All end-use applications can be provided as monolayer or multilayer articles, wherein any layer comprises the hydrogenated block copolymer as described herein. Additional layers may be other polymeric materials including, but not limited to those polymers listed as possible polymers for blending with the rigid hydrogenated block copolymers.

Surprisingly, these highly hydrogenated copolymers are capable of making a wide range of transparent (translucent or opaque with colorants), low color, rigid films; profiles; sheets; coated, injection molded, and blow molded articles having excellent properties at standard and elevated temperatures. The copolymers offer low residuals and extractables, high strength, good thermal, radiation, and light resistance, resistance to polar chemicals, acids, and bases, and retention of properties at elevated temperatures. In addition, these copolymers can be processed without drying, are compatible with other polyolefins, and have low health, environmental and safety concerns.

The following examples are provided to further illustrate and illuminate the present invention but are not intended to limit the invention to the specific embodiments set forth.

EXAMPLES

All hydrogenated block copolymers are hydrogenated to a level of at least 95 percent aromatic hydrogenation.

Example 1

5 Rigid tubing is continuously extruded using a 1.5" (3.8 cm) Killion single screw extruder with 24/1 L/D Barr ET screw, a gear pump, and an 8 mm OD mandrel (6 mm ID) die. The material extruded is a fully hydrogenated styrene-butadiene-styrene copolymer with a molecular weight of 65,000 (19,500 polystyrene end blocks and 26,000 butadiene mid-block) and with high levels of crystallinity in the mid-block. The
10 tubing is extruded at 220°C and is rigid, transparent, with high tensile strength, and good thermal properties.

Example 2

A rotomolded prototype is successfully produced using a small vacuum drying oven and a steel plate. The polymer is a fully hydrogenated styrene-butadiene-styrene-
15 butadiene-styrene pentablock copolymer with a molecular weight of 60,000 (17,000 polystyrene end blocks and 4,500 butadiene mid-block) with a crystalline mid-block. The polymer is first ground to a powder, then placed on the metal plate, and inserted into the oven at a temperature of 230°C for a period of 10 minutes. The plate is removed from the oven, allowed to cool, and the film is removed. The films produced
20 are rigid, transparent, with high tensile strength and good thermal properties.

Example 3

Rigid sheet is continuously extruded using a 1.5" (3.8 cm) Killion single screw extruder with 24/1 L/D Barr ET screw, a gear pump, and a 12 inch (30.5 cm) sheet extrusion die. The materials extruded are two fully hydrogenated styrene-butadiene-
25 styrene-butadiene-styrene pentablock copolymers. The first one has a molecular weight of 75,000 (20,000 polystyrene end blocks and 7,500 butadiene mid-block) and the second a molecular weight of 65,000 (13,000 polystyrene end blocks and 13,000

butadiene mid-block). Both materials have crystalline midblocks. The sheet is extruded at 300°C and is rigid, transparent, with high tensile strength, and good thermal properties.

Example 4

5 Preparation of aqueous dispersion

10 The hydrogenated block copolymer of styrene-butadiene-styrene (MW of 75,000, 80 wt. percent styrene) in the form of a solution of 44% solids in cyclohexane is warmed to 65°C. The heated sample is then transferred and loaded into a preheated disperser tank (65°C). This solution is the disperse phase. The disperse phase is pumped from the tank continuously through an arm of a 0.5" (1.3 cm) i.d. stainless steel tube fitted to a T, at a constant rate of 30 g/min. Concurrently, surfactant, sodium oleate (43 weight % in a solution of 2:1(v/v) Ethanol/Water) is pumped through an arm of 0.125" (0.3 cm) stainless steel tubing fitted to the T, at a constant rate of at 1.1 ml/min. Upon exiting, the merged streams are mixed through a 0.5" (1.3 cm) diameter static mixer. The mixed stream is combined with water at flow rates ranging from 0.8-3.0 mL/min. through a second T fitting. The combined disperse phase, surfactant, and water are mixed together under conditions of shear using an in-line stator rotor mixer (E.T. Oakes) operating at 500-800 rpm. This concentrated emulsion is diluted with additional water in a second inline mixer and the particle size and polydispersity are measured using a Coulter LS-230 light scattering particle size analyzer. The solvent is removed from the resultant dispersion by rotary evaporation, and particle size and polydispersity are measured again, showing substantially the same results. The solids content is adjusted to approximately 51% by the removal of water in vacuo. The final volume average particle size of a 51% solids dispersion is 0.364 μm (polydispersity, 25 $D_v/D_n=1.13$).

Example 5

A pultruded 12mm diameter round rod profile is produced at 1 to 4m/min using a hydrogenated SBSBS pentablock copolymer of Mn 60,000, containing 85 weight percent hydrogenated styrene as the matrix resin and 58 weight % of continuous glass roving (R43S from Owens Corning). Polymer melt is fed from a Colines extruder (60mm diameter screw) through a heated manifold (280°C) directly onto the glass fibers. The wet fibers are subsequently joined and pulled through a shaping and consolidation section (280-260°C), followed by a chilled water cooling die (10°C). The profiles are cut in pieces by a hand saw.

The continuous glass reinforced profiles produced have a shiny, good optical appearance good strength. Upon breakage there is no fiber pull out from the matrix indicating the good impregnation of the fibers with the polymer melt.

Example 6

A hydrogenated polymer having a weight ratio of hydrogenated conjugated diene polymer block to hydrogenated vinyl aromatic block of 25:75 and having a block structure of SBS and where the total average molecular weight (M_n) is 55,000 is blended with a hydrogenated polymer having a weight ratio of hydrogenated conjugated diene polymer block to hydrogenated vinyl aromatic block of 68:32 and having a block structure of SBS and where the total average molecular weight (M_n) is 66,000 in a Brabender Plasticoder at 220°C for 1 to 2 minutes and the resulting blend is pressed into film using a Platen Press at a temperature of 230°C for not more than 1 minute and cooled.

The properties of the Platen Pressed films are shown in TABLE 1.

TABLE 1

		Tensile Yield (MPa)	Ultimate Tensile (MPa)	% Elong.	Tensile Toughness (MPa)	1% Secant Modulus (MPa)	2% Secant Modulus (MPa)
Polymer 25:75	Polymer 68:32						
100	0	To brittle	To brittle	To brittle	To brittle	To brittle	To brittle
62.5	37.5	20.7	30.0	303	59.9	863.9	787.4
50	50	15.2	24.9	299	50.5	672.3	608.5
37.5	62.5	11.2	25.0	314	46.7	531.0	462.4
25	75	6.5	32.4	411	49.6	439.2	317.2
0	100	2.0	22.5	430.6	23.8	36.3	35.7

The resulting Platen Pressed films are optically clear and have good balance of toughness and modulus.

Example 7

A hydrogenated polymer having a weight ratio of hydrogenated conjugated diene polymer block to hydrogenated vinyl aromatic block of 20:80 and having a block structure of SBSBS and where the total average molecular weight (M_n) is 75,000 is blended with a hydrogenated polymer having a weight ratio of hydrogenated conjugated diene polymer block to hydrogenated vinyl aromatic block of 68:32 and having a block structure of SBS and where the total average molecular weight (M_n) is 66,000 in a Brabender Plasticoder at 220 ° C for approximately 1 to 2 minutes and the resulting blend is pressed into film using a Platen Press at a temperature of 230 ° C for not more than 1 minute and cooled .

The properties of the Platen Pressed films are shown in TABLE 2.

TABLE 2

Polymer 20:80	Polymer 68:32	Tensile Yield (MPa)	Ultimate Tensile (MPa)	% Elong.	Tensile Toughness (MPa)	1% Secant Modulus (MPa)	2% Secant Modulus (MPa)
100	0	10.8	25.9	4.13	0.54	924.5	868.5
75	25	18.9	26.0	5.436	0.93	866.2	811.1
68.75	31.25	21.4	18.3	8.3	1.43	709.9	689.2
62.5	37.5	22.3	9.8	13.829	2.07	740.0	716.9
50	50	16.6	20.6	291.0	44.7	581.7	555.1
37.5	62.5	11.5	26.8	358.7	50.4	473.8	455.6
31.25	68.75	9.9	32.4	413.5	58.1	475.2	434.4
25	75	8.2	23.0	355.7	40.7	336.4	297.7
0	100	2.0	22.5	430.6	23.8	36.3	35.7

- 5 The resulting Platen Pressed films are optically clear and have good balance of toughness and modulus.

Example 8

- 10 A hydrogenated polymer having a weight ratio of hydrogenated conjugated diene polymer block to hydrogenated vinyl aromatic block of 20:80 and having a block structure of SBSBS and where the total average molecular weight (M_n) is 75,000 is cast into film on a cast film process where the temperatures are set at 230°C and the casting roll and chill roll temperatures were set at 110°C and the draw rate ranges from
- 15 1 to 20 fpm (30.5 to 610 cm/min.)

The properties of the cast film are shown in TABLE 3.

TABLE 3

Tensile Yield (MPa)	29.6	22.1
Ultimate Tensile (MPa)	35.2	22.1
% Elongation	4.6	1.4
Tensile Toughness (MPa)	1.1	0.16
1% Secant Modulus (MPa)	1765	1531

- 20 The resulting film is optically clear with high modulus.

Example 9

- A hydrogenated polymer having a weight ratio of hydrogenated conjugated diene polymer block to hydrogenated vinyl aromatic block of 20:80 and having a block structure of SBSBS and where the total average molecular weight (M_n) is 75,000 is blended with a hydrogenated polymer having a weight ratio of hydrogenated conjugated diene polymer block to hydrogenated vinyl aromatic block of 68:32 and having a block structure of SBS and where the total average molecular weight (M_n) is 66,000 on a WP ZSK-30 twin screw extruder, where the temperatures are set at 230°C and where the resulting blend is cast into film on a cast film process where the temperatures are set at 230°C and the casting roll and chill roll temperatures are set at 110°C and the draw rate ranges from 1 to 10 fpm (30.5 to 305 cm/min).
- The properties of the cast film are shown in TABLE 4

TABLE 4

	50%/50% Polymer 20:80 / Polymer 68:32		60%/40% Polymer 20:80 / Polymer 68:32	
Tensile Yield (MPa)	17.2	13.8	22.1	17.2
Ultimate Tensile (MPa)	35.2	34.4	14.5	23.4
% Elongation	378	359	107	270
Tensile Toughness (MPa)	70.6	65.9	22.7	48.5
1% Secant Modulus (MPa)	786.0	599.8	1006.6	848.0
2% Secant Modulus (MPa)	730.8	551.6	930.8	758.4

- The resulting films are optically clear and have a good balance of toughness and modulus.

Example 10

A hydrogenated polymer having a weight ratio of hydrogenated conjugated diene polymer block to hydrogenated vinyl aromatic block of 20:80 and having a block structure of SBSBS and where the total average molecular weight (M_n) is 75,000 is cast into film on a cast film process where the temperatures are set at 230°C and the casting roll and chill roll temperatures are set at 110°C and the draw rate is at 2 fpm (61 cm/min). The resulting film is biaxially oriented on a TM Longstretcher machine where the orientation temperature ranges from 135 to 150°C, the stretch rate is 0.2 fpm (6.1 cm/min), and the stretch ratio is 4:1.

The properties of the cast film are shown in TABLE 5.

TABLE 5

	MONO		BIAX	
Tensile Yield (MPa)	29.6	22.1	45.5	45.5
Ultimate Tensile (MPa)	35.2	22.1	88.9	80.7
% Elongation	4.6	1.4	73	102
Tensile Toughness (MPa)	1.1	0.16	39.4	51.8
1% Secant Modulus (MPa)	1765	1531	1958	1758
2% Secant Modulus (MPa)	----	----	1793	1606

The resulting oriented film is optically clear and has excellent toughness and modulus.